NBSIR 74-506

Development of a National Anthropometric Data Base: A Preliminary Study Report

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1. INTRODUCTION

1.1 Background

Requests from various private sectors that the National Bureau of Standards (NBS) initiate a comprehensive, national anthropometric program that would meet the related needs of Commerce and Industry, generated the 22-23 October 1973 "Anthropometric Survey Meeting." At this meeting, attended by representatives of both Industry and Federal agencies, the existing anthropometric data needs of the commerce sector were expressed. Proposals to develop this needed data were submitted by Dr. Robin Herron of the Texas Institute of Rehabilitation and Research (TIRR) at Baylor University, and by Dr. Alex Roche and Mr. Ed Hertzberg of Fels Research Institute.

This meeting stimulated an additional series of requests that the NBS develop a program in this area. Since satisfying such requests would involve sailing into "uncharted waters," the Technical Analysis Division (TAD) of the NBS was asked to perform a preliminary study into the needs, organizations and potential scope and costs which might be associated with a program to develop a national anthropometric data base.

1.2 Purpose

The objective of this preliminary study are to:

a. Identify the national-industrial,-medical, and-research needs with regards to anthropometric data.

b. Assess the degree with which existing anthropometric data can meet these needs.

c. Ascertain the possible scope of a national survey whose goal would be to develop a comprehensive, current anthropometric data base.

d. Identify possible survey formats and evaluate a select set thereof.

e. Estimate the timing and probable costs associated with the scenarios* selected in d.

f. Derive whatever other conclusions are possible, based on this preliminary analysis, that might guide NBS in its future course of actions.

1.3 Scope of Report

Since this study was bounded in time to seven weeks, the analysis made was, of necessity, constrained to a level of detail consistent with that time frame.

In order to cost out the proposed program from amongst the large range of possible plans, three scenarios were selected for analysis. These scenarios, described in Section 3, permitted TAD to achieve reasonable cost and timing estimates for the proposed program, and to draw a number of conclusions regarding its potential format, content and scope (Section 4).

* A "scenario" represented an assumed course of action which, though not necessarily predictive in detail, allows one to derive reasonable estimates of cost and time and to draw other relevant conclusions.

2. PROBLEM STATEMENT

Many segments of commerce and industry have expressed urgent need for a comprehensive set of anthropometric data, representative of all segments of the present U.S. population. The problem, as it arises for the NBS is: what role, if any, should the NBS play in the development of such a data base? Since the anthropometric data needs of the commerce sector and the cost of developing such data both appear to be considerable, the question must be carefully considered before actions are forthcoming.

The need for new and comprehensive anthropometric data is seen from the following observations:

Although some anthropometric measurements have been developed throughout history, modern technology and commerce require select anthropometric data in order that their products may reflect the "real world" needs of consumers (i.e., to introduce the "human engineering factor" into the production process) in the most cost-effective manner. For example, clothing designers and manufacturers need to know the mean, range and distribution of specific dimensions of each body part that is clothed. Typically, the national population is divided into cells, the boundaries of which are designated values of variables such as sex, age, height, weight, and circumference (bust, chest, waist and/or hip). Toy and furniture manufacturers must consider the body form as a function of sex, age, and pose in the design of their products. Toy manufacturers and transportation planners must also concern themselves with biomechanical or ergonomic-type data. In order to develop crash-test dummies that simulate a body's reaction to impact, etc., the Department of

Transportation (DOT) seeks to obtain joint motion range data in addition to sufficient body dimension statistics to permit the development of 5-, 50-, and 95- percentile dummies. Both the Department of Agriculture (DOA) and the National Center for Health Statistics (NCHS) are concerned about health nutrition data. Between these two agencies, many national surveys have been undertaken, each involving a significant number of body measurements.

The National Institute of Occupational Safety and Health (NIOSH), Consumer Product Safety Commission (CPSC) and the Occupational Safety and Health Administration (OSHA), are all interested in anthropometric data so as to permit the design of safer and/or healthier living, work and play environments. These organizations have also funded anthropometric surveys of limited scope in recent years.

The various military branches have performed many, expensive anthropometric and human engineering studies to better clothe and equip servicemen, while the Law Enforcement Standards Laboratory (LESL) at the National Bureau of Standards is presently funding an anthropometric survey to improve: the design of protective gear, clothing and the working environment of law enforcement officers.

In addition to all these Federal agencies, many private companies (such as Sears, Wards, school furniture manufacturers, etc.) have performed anthropometric studies to meet their individual needs.

A summary of the potential users of anthropometric-type data and their specific requirements is presented in Table 1 of Section 3 (Table 1 also indicates which scenarios satisfy the needs of users).

Unfortunately, the anthropometric data generated in previous studies suffer from one or more of the following limitations:

a. The data were obtained for a very select segment of the population and therefore have only limited utility.

b. The data do not include some or all requisite measurements or dimensions.

c. The data are old and, therefore, may not be representative of the present-day population.

d. The methods used to obtain the data, or the conditions under which the data were obtained are suspect or ill defined.

e. The statistical significance of the data is not detailed, or is not satisfactory.

These drawbacks appear to be attributable to two basic considerations. First, no single agency has been assigned the task of developing a comprehensive set of anthropometric dimensions for the U.S. population. Second, the collection and analysis of anthropometric data, truly representative of the entire U.S. population, is an expensive, time-consuming and exacting proposition,requiring the establishment of a planned, structured and comprehensive program.

To further complicate the problem, it must be noted that,within the next decade, many industries (such as the clothing and transportation industries) will be going metric. Much of the existing anthropometric data are presented in "customary" U.S. units (e.g., inches, foot-pounds, etc.). Since the existing anthropometric data may not properly reflect the body dimensions of the present population,

the period of metric conversion would be the ideal time to also revise the sizing cell structure,* as well as the proportioning of the dimensions within each cell.

*See first part of Appendix A for existing sizing cell structure of clothing industry.

3. COSTING SCENARIOS

3.1 Introduction

In order to "cost-out" a comprehensive, national, anthropometric survey that, though responsive to the wishes of its sponsors (funding sources) would also be mindful of the long-range, overall needs of major potential users of such data, it was necessary to make pertinent assumptions as to the survey's most likely scope, content, and format.

The proposals submitted by Fels Research Institute (Appendix B) and by the Texas Institute of Rehabilitation and Research (TIRR) (Appendix C) were used as starting points for evolving likely survey scenarios. These proposals were modified as a result of extensive discussions with representatives of the proposing institutions, and with many potential users, as well. Engineering firms that would assist in the development and fabrication of pertinent hardware were also contacted. (Contacts made in the course of conducting this project are listed in Appendix D.)

Analysis of the problem led to the development of three national anthropometric survey scenarios. These three scenarios are considered to be the most viable and cost-effective alternatives in light of the needs conveyed by contacted potential users. Similarly, each overcomes to some degree, the flaws of previous surveys.

Due to the magnitude, scope and cost of the proposed scenarios, an administering agency or group needs to be established before the survey's inception. This group (or agency) would be responsible for such items as:

a. Fostering a consortium of interested (Federal, industrial, etc.) parties who would participate in the funding of the program.

b. Evaluating and selecting among the alternative program scenarios, and modifying the scenario-of-choice where it is deemed desirable.

c. Initiating and administering the research and actual survey through disbursements of funds (contractual agreements) and guidance to the contractee(s).

d. Maintenance and dissemination of the data generated within the program.

e. Updating and expanding the data base at periodic intervals in response to user requests.

As all three scenarios contain many identical elements, these commonalities are presented, for conciseness, in Paragraph 3.2. The unique details of each selected scenario are found in Paragraphs 3.3 through 3.5.

3.2 Common Scenario Elements

a. After careful analysis of the problem, it was considered imperative to the success of any national anthropometric survey that it run in tandem with NCHS' survey. The next such Health and Nutrition Examination Survey ("HANES") is scheduled for early 1976. The reasons for requiring such a linkup of systems are:

(1) In order to generate a data base representative of the entire national population, it will be necessary to develop a sampling plan involving many thousands of people of all ages, distributed throughout the states. The most experienced organization for developing a sampling plan of such magnitude is the Census Bureau. The effort required to develop such a plan is quite extensive (and expensive). Such a plan, involving a sample of 28,000 people distributed over about 65 sites throughout the nation is developed by Census for each NCHS survey as part of a continuing agreement between these two agencies. Census may be reluctant to undertake an additional sampling plan effort, since it would appear to represent a duplication of effort and, therefore, an avoidable expenditure of taxpayer dollars.

(2) The potential duplication of effort is compounded since Census also acts as the contacting agent for NCHS. At each site which NCHS visits, Census "interviewers" contact the selected subjects and set up appointments for them with the NCHS field staff. Thus, Census has developed expertise in this area which should be utilized.

(3) Even where the sampling plan is carefully designed to produce an unbiased data base, an indeterminate bias may be introduced into the data if the "Capture Ratio" (the fraction of people actually examined to the total number contained in the sampling plan) falls below $\sim$ 75%. At the present time NCHS, which can offer selected

subjects a thorough, free, medical examination, just achieves this minimal capture ratio (75%). The proposed anthropometric survey, if run independent of NCHS, could not offer prospective subjects this examination and, therefore would most likely suffer a much lower capture ratio.* This objection is the most severe as it would vitiate much of the rationale for this program.

(4) Since both NCHS' survey and the potential anthropometric survey involve the obtention of demographic and personal data from each subject, this again would represent a duplication of effort.

(5) NCHS has two field teams each containing four vans which are designed to include facilities for anthropometric examinations. The obtention of trailer sites and of electricity and water, etc. for these trailers is arranged by NCHS field crews. To duplicate such effort and not utilize this NCHS experience would appear to be unwise.

(6) Finally, the potential exists for correlating some of the medical factors developed in the courses of the "HANES" examinations with various measured body dimensions, or biomechanical quantities.

b. As in recent HANES surveys, the anticipated target sample is about 28,000 which, for a capture ratio of 75%, gives a

*Although one might argue that a substantial monetary incentive could be offered all prospective subjects (NCHS presently pays its subjects a nominal fee of $10) such an action could produce a high capture ratio, but an extremely biased sample!

sample size of about 21,000 people.* These will be distributed over 65 sites, each of which contains between 300 to 600 people (in the sampling plan).

c. All major segments of the present U.S. population are expected to be included in the sampling plan. Among the demographic variables that occur here are: sex, race, ethnic origin, socio-economic and occupational class, as well as educational level. Subjects should range from 1 or 2 through 74 years of age.

d. Pertinent demographic, historic, and medical data that NCHS obtains should be made available to the survey for inclusion into the anthropometric data base, albeit in a form that will satisfy anonymity requirements. Similarly, the anthropometric program would probably be expected to supply NCHS with the dimensions they require.

e. An extreme effort should be made to connect up with the HANES survey scheduled to begin in early 1976, as subsequent surveys probably will not begin until 1978 or 1979. The field work for all three scenarios is assumed to begin in early 1976. Two survey teams, each to be fielded for three years, and typical daily flow rates of from 10 to 20 subjects are anticipated.

f. All selected scenarios involve innovative techniques and instrumentation. Before the actual field measurements get underway and, indeed, before NCHS could even consider including any such novel program into one of its surveys, it will be necessary to perfect such techniques and instruments

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*That this sample size is probably adequate, at least for the needs of the clothing industry, can be seen from the statistical analysis given in Appendix A.

to such a point that their viability, reliability and accuracy can be clearly demonstrated. Furthermore, NCHS will probably be reluctant to allot more than a 15 to 20 minute block to these anthropometric measurements. It is imperative, therefore, that the required techniques be streamlined so that as many dimensions as are required, or possible, can be obtained within the allotted time. It may be possible to conserve both field cost and time by prior determination of what anthropometric dimensions are highly and reliably correlated with other dimensions involving one or more poses. That is, only a specific set of dimensions are possible from a given subject pose. The required set of dimensions may, therefore, necessitate the use of multiple poses. In scenarios A and C analysis of multiple sets of stereo-pair photos would be necessary to analyze multiple poses. Since such analysis is both expensive and time consuming it is imperative to limit the number of stereo-pair photos analyzed, per subject, to one, (although a back-up set of photos is recommended). Correlations obtained during the pilot stage of the program could, therefore, affect the pose selected for photography and would likely reduce the number of residual (residual = required--obtained from biostereometric analysis of one set of photos) dimensions that will be obtained by conventional anthropometric techniques. For scenario B, this could mean the difference between being able to develop certain data or not, within the allotted subject-examination time blocks.

In short, a pilot study is required. If the decision is made to attempt a link-up with the 1976 HANES survey then, theoretically, such a study should start yesterday! Unfortunately initiation of such a study assumes the prior selection of a scenario and the obtention of adequate funding. The feasibility and viability of the selected technique and its associated instrumentation would have to be demonstrated by early 1975 if there is to be any possibility of inclusion of the anthropometric program in the 1976 HANES survey! Appendix E

contains an expanded list of factors, common to all proposed scenarios, that the pilot study should examine.

g. Management and review of the overall project are assumed to fall to a governmental agency. The possibilities here include NBS, NCHS/DHEW, Census, various institutes within the National Institutes of Health (NIH), the National Science Foundation-National Research Council (NSF-NRC), Commerce, etc. The cost of this management is assumed to be agency-independent.

h. This administering agency will, assumedly, canvass prospective users of anthropometric data in order to develop both a funding consortium and a list of desired dimensions, possibly ordered as to degree of need or utility. The particular data needs of various industries and Federal agencies are presented in Table 1. This Table also indicates which scenarios will satisfy the various users' needs. Contractural agreements with the groups selected to develop the data base must then be made. Contractee guidance, periodic progress reports to the funding sources and the dissemination of output data will be required. Maintenance (probably in computerized form) of the data base for instant recall or manipulation, as well as data base updating, could also fall within the administering agency's mandate.

i. Output data should be presented, where possible, in both "customary" U.S. and metric units.

j. Fel's proposal (Appendix B) assumes an overhead rate of 65%* while TIRR's overhead (see Appendix C) runs at about 32% of salaries and wages. For comparison TAD's overhead rate is 100%. As a compromise all overhead rates were fixed at 80% in the costing analysis, and overhead uncertainties adjusted accordingly (see Appendix F).

*Allowance for FICA and major medical adds another 10% to this figure.

Table 1. USER DATA REQUIREMENTS, AND THEIR FULFILLMENT BY THE CONSIDERED SCENARIOS

Required Anthropometric Data	POTENTIAL USERS														
	INDUSTRIES					GOVERNMENTAL AGENCIES									
	Clothing	Recreation	Appliances Furniture	Transportation	Housing	DHEW	NIH	CPSC	NIOSH/ OSHA	DOT	CBT	LESL	DOA	DOD	DOC
Lengths, Girths, Arcs	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C
Skeletal Age	--	--	--	--	--	A,B,C	A,B,C	(A,B,C)	--	--	--	--	--	A,B,C	--
Reach	--	A,B,C	A,B,C	A,B,C	A,B,C	--	--	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	--	A,B,C	A,B,C
Sitting Dimensions	(A,B,C)	A,B,C	A,B,C	A,B,C	--	--	--	A,B,C	A,B,C	A,B,C	--	A,B,C	--	A,B,C	A,B,C
Extremity Details	A,C	A,C	A,C	--	--	(A,C)	(A,C)	A,C	A,C	--	--	A,C	--	A,C	--
Body Fat vs. Muscle	--	--	--	--	--	A,B,C	(A,B,C)	--	--	--	--	--	A,B,C	A,B,C	--
Demographic	A,B,C	A,B,C	(A,B,C)	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	(A,B,C)	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C
Body Segment:															
Volume	A,C	--	--	--	--	A,C	A,C	--	--	--	--	--	(A,C)	--	--
Surface Area	--	--	--	--	--	(A,C)	(A,C)	--	--	--	--	--	--	--	--
Center of Mass	--	A,C	(A,C)	(A,C)	--	--	--	A,C	A,C	A,C	--	--	--	(A,C)	--
Moment of Inertia	--	A,C	--	A,C	--	--	--	A,C	A,C	A,C	--	--	--	(A,C)	--
Grip Strength	--	X	--	X	--	X	X	X	X	X	(X)	(X)	--	X	(X)
Arm Push, Pull	--	X	X	X	--	X	X	X	X	X	--	X	--	X	(X)
Leg Push	--	X	X	X	--	X	X	X	X	X	--	X	--	X	(X)
Endurance	--	X	--	X	--	X	X	X	X	X	--	X	X	X	--
Joint Motion Ranges	--	X	X	X	--	X	X	X	X	X	--	X	--	X	--
Biomechanical Limits	--	X	X	X	--	X	X	X	X	X	--	X	--	X	--

LEGENDS

--	Data Not Required by User
A,B,C	Data Required and Fulfilled by A,B, and C Scenarios
(A,B,C)	Data May Be Useful and is Fulfilled by A,B, and C Scenarios
X	Data Required But is Not Fulfilled by Any (Considered) Scenario
(X)	Data May Be Useful But is Not Fulfilled By Any (Considered) Scenario

k. A major portion of the body dimensions that will probably be measured in any scenario are contained within the list submitted by the sizing sub-committee of the Mail Order Association of America (MOAA). This list, which has been included into the report as Appendix G, while probably going a long way to satisfy the needs of most clothing-related industries must, no doubt, be supplemented by similar type lists drafted by the other potential-user industries and agencies. Each such list should be ordered by degree of need, and by poses required. The final selection will probably depend upon: time and costing constraints (which are a function of scenario), degree of participation in the program funding by the requesting group, concensus of need among the groups, uniqueness of a dimension and its correlation to other, accepted dimensions, etc.

l. No payment to subjects has been included in costing any of the scenarios. It is assumed that NCHS will assume this responsibility. If the anthropometric program area is requested to augment the fee given subjects, then the total project cost could be incremented by about 21K x $5 = $105K.

3.3 Factors Unique to Scenario A (TIRR)

This scenario basically involves the use of photogrammetric techniques to determine body form and dimensions. Briefly stated, a subject is dressed in a uniform designed to conform with the body surface and not distort it. The subject then stands between two vertical rods that are so designed, marked and positioned as to accurately define the X, Y, and Z axes within the body plane. One set of stereo-pair cameras is located directly in front of the subject and another set is directed at his back. Each stereo-pair camera set is mounted on a tripod with a projector that produces a fine pattern of connecting lines on the subject. The subject is then posed and, when set,

simultaneous front and back stereo-pair photos are taken. A back-up set of photos will also, probably be taken. All film will be developed on site. Photos will also be taken of calibrated dummies on a daily basis to check the accuracy of the entire process. Once processed and checked to confirm that the photographic equipment appeared to be in satisfactory working order all negatives would be mailed back to Houston for further analysis. The next step in this biostereometric approach involves (semiautomated) stereo plotting, at which time the X, Y, and Z coordinates of preselected points on a subject are derived from the stereo-pair negatives. These selected points are then used to solve a set of simultaneous equations that determine the holistic[a] body form. The conversion of the holistic data into the required body dimensions can also be performed by TIRR or could be assigned to another qualified group. Stratification, sorting, and statistical analyses on the body dimension data would be done by the administering agency or a contracted group. The biostereometric technique is described in more detail in Appendix C and the costing factors for each aspect of scenario A is found in Appendix F.1. These factors and their costs are presented within a time-frame matrix in Figure 1. The total cost of the anthropometric survey program using scenario A is estimated at \$5.2M, while the 95% Confidence Interval (CI)[b] for the cost is \$4.3M to \$6.1M.

The following questions are considered to be unique to this Scenario (and Scenario C) and should be addressed within the aforementioned

---

[a] The coefficients, when plugged into this set of equations permits one to accurately determine the coordinates (say X, Y, Z) of any point on the body. Computation of any body dimension, cross section, body-segment volume or surface area, etc. are also possible from this holistic equation set.

[b] This CI was obtained by a non-rigorous approach (due to the asymmetric nature of several of the cost factors) which is described in Appendix H.

FIGURE 1. SCENARIO A, ESTIMATED TIME-COST MATRIX

(All Costs are in Thousands of Dollars)

		Start Pilot Study		Start Survey			End Survey		End Project	Totals	
Factor	Description	'75[a]	'76	'77	'78	'79	'80	'81	Expected	Low[e]	High[e]
Administration, Overall	Labor	31	31	31	31	31	31	31	217	180	240
	Travel	5	5	4	3	3	3	2	25	20	30
Administration, Biostereometrics	Labor[b]	36	36	36	36	36	13	--	193	140	220
	Supplies/Travel	5	5	6	6	6	2	--	30	25	35
Research	Labor[b]	100	110	110	110	27	--	--	457	310	530
	Materials	70	70	35	35	10	--	--	220	180	260
Field Measurements	Labor[b]	--	7	68	68	68	7	--	218	200	300
	Equipt./Per Diem	16	72	83	84	77	--	--	332	100	440
Initial Computations	Labor[b]	15	15	15	15	15	7	--	82	80	90
	Computer	30	70	200	100	5	15	--	420	220	1220
Stereo-Plotting	Labor[b]	--	18	182	182	182	18	--	582	430	730
	Equipt./Space	120	292	--	--	--	--	--	412	330	440
Final Computations	Labor[c]	--	--	--	9	31	40	24	104[f]	85	125
	Computer/Travel	--	--	--	--	51	152	152	355	250	450
Documentation	Printing	--	--	--	--	--	--	20	20	15	40
Overhead[d]	Admin. Agency	25	25	25	24	25	25	25	174	140	190
	Initial Phase[b]	121	149	329	329	262	36	--	1226	530	1380
	Final Phase[c]	--	--	--	7	25	32	19	83	25	100
								Grand Totals[e]	5150	4260	6050

(a) These columns each represent a Fiscal Year so that, for example, the pilot study is assumed to start 7.1.74.

(b) All "Labor" factors footnoted "b" comprise "Initial Phase" labor.

(c) The Labor factor footnoted "c" comprises "Final Phase" labor.

(d) Overhead is computed as 0.8 x labor costs and has been separated according to responsible agency.

(e) The high and low values given here represent estimated 95% (± 2 standard deviations) confidence limits. The computations and assumptions that lead to the high and low totals are described in Appendix H.

(f) Analysis for about 120 body dimensions is assumed.

pilot study:

a. What anatomical points can be reliably and accurately estimated either by visual or optical examination of stereo-pair negatives? Note that all remaining requisite anatomical points will have to be pre-marked by trained field workers.

b. To what degree can stereo-plotting of the negatives be automated? How best should this be done?

c. If dimensions of the soles or feet are needed how best may they be obtained?

d. What pose permits the obtention of maximum useful data from front and back stereo-pair photos?

e. Can the photographer accurately estimate when the subject is correctly posed? If not, do double sets of photos give a sufficient margin of safety?

f. Does the field worker always know if his photographic equipment is working satisfactorily? If significant exceptions occur here, safeguards to either prevent or detect malfunctions,must be developed and installed.

3.4 Factors Unique to Scenario B (Fels Research Institute)

As envisaged, this scenario would have the survey performed by more traditional anthropometric techniques. These techniques involve the use of tape rules, anthropometers (skin-fold calipers, etc.), etc. as well as several, somewhat novel, electro-mechanical devices that should permit the rapid measurement of certain dimensions, such as body segment lengths. Body arcs, girths, etc. will be measured with tape measures. Body segment: centers of mass (CM), moments of inertia, volumes, surface areas, etc., measurements will not be possible

here; however, the total body CM can be determined by use of a specially designed chair, already in use. All the above measurements are assumed to be output in directly usable dimensions and, with the exceptions of data collation and conversion to conventional U.S. units (data assumed to be taken in metric units), are in suitable form for statistical analysis. Since a joint effort with NCHS is assumed here, Fels' "Suggested Plan Summary" (Appendix B) must be somewhat modified. In particular, "Data Gathering" will take three years, rather than the estimated two years. This will modify Fels' estimated costs somewhat. As with Scenario A (paragraph 3.3) it will not be considered necessary to purchase a special set of vans to house these anthropometric facilities; rather, use of NCHS' vans is envisaged. However, it should be noted that a fair amount of personnel and measuring equipment are required in Scenario B. So much so, in fact, that the use of extensive semi-automated data recording equipment could put the physical dimensions required by this scenario beyond NCHS' available space. A set of vans with their associated costs would then be required. This would add an estimated $86K cost to Scenario B. The automatic data recording equipment envisaged by the Fels Group appears somewhat unwieldy. In particular, the automatic transcription of data, from the semi-automatic anthropometers to punch cards, could result in the generation of more than 200,000 cards -- which is considered unmanageable; magnetic tapes and tape drives have been substituted. The biostereometric operations mentioned in Fels' plan (Appendix B) is omitted here, but a joint TIRR-Fels venture is described in Scenario C, Paragraph 3.5. Unlike Scenario A, it is assumed that all data analysis will be done at and by Fels' staff. The costing of Scenario B is detailed in Appendix F.2. The total estimated cost for

Scenario B is $2.4M, while the 95% CI for the total program cost is $2.3M to 2.6M.* Individual factor costs, within a time-frame matrix, are found in Figure 2.

The factors that would be unique to the pilot study, to be made within Scenario B, are:

a. Optimize the design and application of the envisaged electro-mechanical anthropometers.

b. Optimize recording data with regards to their dimensions, timing, cost and manageability of output.

c. Determine from the pilot study data (as well as pertinent literature from past surveys), which body dimensions can be accurately and reliably extrapolated from other, "basic" dimensions, (i.e., "Basic" dimensions are those that are considered to be requisite to the data base).

d. Train field workers.

3.5 Factors Unique to Scenario C (Joint TIRR, Fels Effort)

This scenario is, in essence, identical to Scenario A, except that personnel from Fels: perform the anatomical marking; take the measurements not derivable from photogrammetry; and are responsible for the "Final Computations" referred to in Paragraph 4.2. Unlike Fel's proposal (Appendix B), however, the brunt of data obtention responsibility would fall on TIRR, while the statistical data analysis would fall to Fels. In effect, this scenario draws on the strong points of these two institutions.

In order to prevent possible conflicts here, these two groups would be contracted by the administering agency to perform designated tasks

*This CI was obtained by a non-rigorous approach (due to the asymmetric nature of several of the cost factors) which is described in Appendix H.

FIGURE 2. SCENARIO B, TIME/COST MATRIX

(All Costs are in Thousands of Dollars)

Factor	Description	Start Research '75[a]	'76	Start Survey '77	'78	'79	End Survey '80	'81	End Project Totals Estimated	Low[c]	High[c]
Administration, (Overall Project)	Labor	31	31	31	31	31	31	31	217	180	240
	Travel	4	4	3	3	3	2	1	20	15	25
Anthropometry, Administration	Labor	48	48	48	48	48	48	48	336	285	385
	Materials/Travel	10	10	7	7	6	5	5	40	30	50
Research	Labor	(Included under "Computations" Factor)									
	Equipment	(Included under "Field Units" Equipment Factor)									
Field Units	Labor	--	18	88	88	88	--	--	282[d]	250	310
	Equip./Per Diem	50	157	95	95	94	--	--	490	435	545
Computations	Labor	--	21	--	25	36	36	29	147	115	175
	Computer Costs	--	5	--	--	10	60	30	105[d]	75	175
Documentation	Printing	--	--	--	--	--	--	20	20	15	40
Overhead[b]	Fels'	38	70	109	129	138	67	61	612	490	675
	Admin. Agency	25	25	25	25	24	25	25	174	140	190
								Grand Total[c]	2443	2280	2565

(a) These columns each represent a Fiscal Year so that, for example, the pilot project is assumed to start 7.1.74.

(b) Overhead has been computed as 0.8 x labor costs and has been separated according to responsible agency.

(c) The high and low cost estimates given here represent estimated 95% (±2 standard deviations) confidence limits. The computations and assumptions that lead to the high and low totals are described in Appendix H.

(d) Measurement and analysis of between 60 and 100 dimensions is assumed here.

and they would each be responsible to this administrator. A general description of this scenario, exclusive of the above modifications can be obtained from Paragraph 3.3 and Appendix C. A detailed account of the expected costs is given in Appendix F.1, and is modified by F.3. The time/cost matrix modifications that must be made to Scenario A to give us a Scenario C equivalent are given in Figure 3. Total program cost here seen to be about \$5.2M with a 95% CI of \$4.3M to 6.1M.*

3.6 Comparative Analysis of Selected Scenarios

Since it it assumed that one of the three selected scenarios may represent a starting position from which a final program plan will derive, it is useful to compare the merits and faults of each. Such a comparison is presented in Table 2, and may facilitate the selection of a suitable framework in which to develop the ultimate program plan.

*This CI was obtained by a non-rigorous approach (due to the asymmetric nature of several of the cost factors) which is described in Appendix H.

FIGURE 3. SCENARIO C, ESTIMATED TIME/COST MATRIX AS A PERTURBATION OF THE SCENARIO A MATRIX, (FIGURE 1.)

(All Cost are in Thousands of Dollars)

Factor	Description	Start Research '75[a]	'76	Start Survey '77	'78	End Survey '79	'80	'81 End Project	Totals Expected	Low[b]	High[b]
Totals, Scenario A	Cost Factors[c]	574	905	1124	1039	854	381	273	5150[d]	4260	6050
Consultant	Labor	4	4	--	--	2	4	2	16	13	24
	Travel	1	1	--	--	--	1	--	3	2	4
Overhead	Fels Institute	2	2	--	--	2	2	2	13	8	18
								Grand Totals[b]	5182	4290	6080

(a) These columns each represent a Fiscal Year so that, for example, the pilot project is assumed to start 7.1.74.

(b) The high and low cost estimates given here represent estimated 95% (± 2 standard deviations) confidence limits. The computations and assumptions that lead to the high and low totals are described in Appendix H.

(c) Obtained from Figure 1.

(d) Analysis for about 120 body dimensions is assumed here.

Table 2. APPARENT ADVANTAGES/DISADVANTAGES OF SELECTED SCENARIOS

Factor	Scenario A	Scenario B	Scenario C
Number of dimensions that will probably be obtainable.	Extensive, but limited by photographed pose and by "Blind Spots" (Body areas that photos cannot observe for given pose). (a)	Limited to those dimensions that can be obtained within the allowed examination time block, and to demonstrated, correlatable dimensions.	Same as for Scenario A
Required Time Block	Minimal	Probably greater than that alloted by NCHS.	Same as for Scenario A
Subject Handling	Minimal (a), though some subjects may object to being photographed. Also attire used here may be less modest than with Scenario B.	Considerably greater than with Scenarios A or C.	Same as for Scenario A
Recovery of Errors	If photos are satisfactory all other errors are recoverable. Scenario includes duplicate photos per subject (a).	Those measurements that were in error or are suspect cannot be recaptured.	Same as for Scenario A
Overall Project Cost(b)	About $5.2M ± 900K For about 120 dimensions.	About $2.44 M ± 150K For 60 to 100 dimensions.	About $5.2M ± 900K For about 120 dimensions.
Program Duration	About 7 years from inception.	Same as, or as much as 2-3 months shorter than either Scenario A or C.	Same as for Scenario A
Measurement of body segment: centers-of-mass, moments-of-inertia, volumes and surface areas.	Are already possible using biostereometrics.	Cannot be readily accomplished within a HANES-linkup scenario.	Same as for Scenario A
Measurement of both left and right limbs and extremities. Also body deformities.	Can readily be done.	Both Right and Left data not possible within assumed time frame-work.	Same as for Scenario A
Can dimensions, not within original plan be generated after survey completed?	Yes, as long as they are derivable from the photos taken.	No, unless they are highly correlated to measured dimensions.	Same as for Scenario A
Amount of technique and instrumentation development required (prior to survey).	Considerable - so much so that it is questionable if the biostereometric Scenario viability could be satisfactorily demonstrated by early '75 - when inclusion or exclusion of survey must be decided by NCHS.	Novel anthropometers also required here, however, they are not nearly as complex, and some development and use has already occurred here. (c)	Same as for Scenario A
Research Staff	Have hard core - very bright, eager.	Assume the same here	Same as for Scenario A
Prior survey experience that can be brought to bear.	TIRR does not have extensive background in survey-type work.	Fels has considerable experience in making anthropometric surveys.	Combination of remarks for Scenarios A and B
Science of Anthropometry	Could potentially advance this science more than all previous improvements over past 2000 years.	Could result in marked improvement in design of semi-automated anthropometrics.	Same as for Scenario A
Accuracy of Data	Dimensions obtained by biostereometrics should be accurate to ∿.001".	Measurements can be quite precise but may be examiner-limited.	Same as for Scenario A
Dummies	Cross-sections generated at, say, 1" heights permit fabrication of truly representative dummies/mannikins.	Only gross features for dummies are developed in this scenario.	Same as for Scenario A

(a) The exception in all these cases being that small subset of dimensions measured in Scenario A by Conventional Anthropometric Means.

(b) This CI was obtained by a non-rigorous approach (due to the asymmetric nature of several of the cost factors) which is described in Appendix H.

(c) For example, at the University of Michigan automated calipers and tapes are in current use.

4. FINDINGS AND CONCLUSIONS

In lieu of actual recommendations, this section summarizes major findings and conclusions arrived at by analysis of the problem or questions implied in paragraph 1.2. Other serious problems still to be addressed are also listed for the readers consideration.

The most significant findings are:

a. There is a justifiable need for a comprehensive national anthropometric survey, based on a well conceived and executed sampling plan. This survey should include all segments of the U.S. population, and the accurate dimensions so generated would reflect the needs of as large a consortium of potential users as is deemed feasible.

b. There appears to be a "blind spot" in the perceived missions of the various Federal agencies. In particular, no U.S. agency was found whose mission included -- explicitly, implicitly, or traditionally -- the development of a National Anthropometric Data Base.

c. Sorted statistical anthropometric tables would appear to fall within the realm of "Standard Reference Data." Several sections within NBS have missions or projects, which could be advanced by the introduction of suitable anthropometric data. Included here are sections 400.09, 401.02, 401.03, 411.01 and elements within the CBT.

   On the other hand there would also appear to be sufficient justification to consider Census, NCHS (DHEW), NIH, or even NSF-NRC as the heirs to such a project.

d. As explained in Appendix H, a statistically meaningful national anthropometric survey is <u>only</u> viable if linked to a NCHS survey. The next such (HANES) survey is scheduled for 1976 and should capture about 75% (21,000) of the 28,000-person sampling plan designed by Census. This survey will last about 3 years and will involve about 65 sites throughout the country.

e. A pilot study will be necessary, whatever the survey method or format. Since there are many questions that must be answered, correlations that must be ascertained, and software and hardware that must be developed before any of the considered scenarios could be considered acceptable by NCHS, (assuming all other objections, etc. were overcome), the pilot study associated with a selected scenario <u>must begin immediately</u>. If funding for such a pilot study is not forthcoming in the next few months, then one probably can forget about joining up with NCHS' '76 survey and the next train doesn't leave till '78 or '79!

f. The estimated total cost and time required to complete each selected scenario are:

Scenario	Total Cost: Expected	Total Cost: 95% Confidence Limits, Lower	Total Cost: 95% Confidence Limits, Upper	Total Time (Years)
A	$5.2M	4.3M	6.1M	7→7.2
B	2.4	2.3	2.6	7
C	5.2	4.3	6.1	7→7.2

Although Scenarios A and C are more than twice as expensive as Scenario B, in the long run the use of biostereometrics could produce a larger set of dimensions, (see Table 2) which would be capable of servicing a much wider constituency, as is evident from Table 1. Furthermore, a good part of the extensive cost of this survey will go towards laying the groundwork for future anthropometric surveys. Unless a still more novel technique becomes available in the intervening years, biostereometrics will likely be the preferred anthropometric tool for the last quarter of the 20th Century.

*This CI was obtained by a non-rigorous approach (due to the asymmetric nature of several of the cost factors) which is described in Appendix H.

g. If, after considering this Study/Report, NBS decides to investigate further, then a more detailed project will be required to precisely determine the proposed survey contents, format and cost. In such a case, some funding should be immediately allocated for advancing the most likely scenario. Funding could come from an "interested" governmental agency. In the long run, however, it appears that significant funds will also have to come from the private sectors of commerce and industry. There are many precedents for this sort of arrangement. For example, the Secretary of Commerce is authorized to receive gifts from private groups or individuals and to use these gifts to facilitate work pertinent to the mission of DOC. The potential sources of funds are, in part, identified by the user requirements/ fulfillment matrix, Table 1. Among its many tasks the administering agency may have to develop and supervise a funding consortium.

h. Assuming a link-up to NCHS' '76 survey, meaningful data will not be forthcoming until at least 1980 and, more likely, not before 1981-2! It is not clear whether the potential funding sources within industry would be prepared to wait so long.

i. Obtention of: joint motion ranges, grip strength, leg push, arm push-pull, endurance or other biomechanical ergonomic data should <u>not</u> be included in the proposed survey as they would significantly augment the time block requirement for each subject. Also, the electromechanical instrumentation required for most of these measurements is in the development stage and would further add to the costing and timing problems

already cited. The governmental and commercial groups that are interested in obtaining such data could do so using a much smaller sample size. On the other hand: reach, skin fold, skeletal age, body segment-volumes: center-of-mass and moments-of-inertia, as well as some or all of the anthropometric measurements listed in Appendix G should be included in the survey plan (again note Table 1).

j. The anthropometric and biomechanical data generated by this survey should be output in both "customary" U.S. and metric units. The additional cost of dual computations and additional documentation will be more than compensated by the increased utility and universality of the data.

k. The (statistically meaningful) sample size required to satisfy the data needs of the clothing industry (probably the potential user who has the most extensive and intensive need for anthropometric data) is estimated (in Appendix A) to range from 10,700 to 17,700 subjects. This range is well within the sample size that is anticipated to be captured in the assumed scenarios. The requisite sex, age, geographical, etc. subsamples will probably also be attained.

Assuming a decision is made to proceed with a National Anthropometric Survey, and that a NCHS linkup is acceptable to all concerned, then the most serious problems still to be addressed include:

a. Location of adequate sources of funding.
Stop-gap monies must be immediately obtained so that the: administrating, pilot study, and advanced program analysis groups (below) can be funded until the actual funding consortium is established.

b. Assumption of a tentative, "most-likely" scenario so that immediate funding may be initiated of those aspects of a pilot study requiring resolution by early 1975.

c. Designation of an administering group.

d. All funding sources and other prospective users of anthropometric data must be contacted to obtain lists of body dimensions, ordered by degree of need, pose, etc. The administering agency must then combine these lists to form a tentative list of dimensions to be obtained by the major survey. This list, which will be a function of the assumed scenario, should be overambitious. Triming, based on the pilot study findings, and other considerations can come just before the actual survey begins.

e. A more detailed analysis of the survey program should be initiated. Accurate costing, scope and survey format predictions must be developed. This step may have to preceed establishment of the funding consortium.

APPENDIX A

Optimal Sampling Dimensions for the Proposed Anthropometric Survey

Appendix A. <u>Optimal Sampling Dimensions for the Proposed Anthropometric Survey</u>

If the proposed survey is to benefit the Clothing Industry, (a major anthropometric survey proponent, potential sponsor, and user) the following factors must be considered.

1. <u>Sampling Factors</u>

Principal variables that must be considered are sex and age. Thus, the population can be divided into the following cells:

(a) (0, 3 yrs., 6 mos.)*; unisex

(b) (3, 20, 1 yr.); for each sex

(c) (20, 80, 5 yrs); for each sex

Compartments for (a) might include:

0 →< 6 mos., 6 →<12 mos., ... 30→ < 36 mos.

Compartment for (b) might include:

3 yrs.→ < 4 yrs., 4 yrs.→ < 5 yrs., ... 19 yrs. →< 20 yrs.

Compartments for (c) might include:

20 yrs.→ < 25 yrs., 25→ <30 yrs., ... 75 yrs.→ <80 yrs.

2. <u>Utilization Factors</u>

a. <u>Children</u>, 0→5 yrs., Unisex

First sort by circumference/weight variable - into one or two compartments. Within each compartment sort by height in 1" intervals (i.e., 19", 40", 1")

This generates 22 or 44 compartments.

b. <u>Juveniles</u>, (6 →<14 yrs.) Males & Females Handled separately, but in a similar manner. First sort by circumference/weight variable into (probably) 3 groups (e.g., "slim," "regular," "chubby"). Within each group sort by stature: 40", 62", 1" or 2". Thus, this age group includes 2 x 3 x 19 = 114 or 2 x 3 x 10 = 60 compartments.

---

*This notation is used to concisely describe both age and sizing cell dimensions. Thus, in the number sequence $(X_L, X_u, \Delta X)$ X_L represents the lower and X_u the upper cell boundaries while ΔX is the individual cell width.

c. Adult Males, ($\geq 14 \rightarrow < 80$ yrs.)

First sort by stature into 3 to 5 groups (# of groups here depends on % of people falling outside of "reg" and "tall" classifications). If either % is appreciable will have to add 1 or 2 additional groups to standard 3 groups (reg., ave., tall). Within each stature group would sort according to circumference-type measurement (A combination of chest, waist & hip circumferences). Compartments here defined by: (34", 50", 1" or 2"). (Thus $\begin{bmatrix}3\\5\end{bmatrix} \times \begin{bmatrix}9\\17\end{bmatrix}$ gives from 27 to 85 compartments).

d. Adult Women ($\geq 14 \rightarrow < 80$ yrs.)

First sort by stature into 3 to 5 groups as with adult males. Within each stature group sort by circumference-type measurement (a combination of bust, waist and hip circumferences). Compartments here defined by: (32", 56", 1-1/2" or 2")

(Thus $\begin{bmatrix}3\\5\end{bmatrix} \begin{bmatrix}13\\17\end{bmatrix}$ gives from 39 to 85 compartments).

Once the sampled population is so compartmentalized the next step will be to statistically estimate the various dimensions (See Appendix D), means and standard errors of these means, etc., for each cell. From the cell dimensions* and required accuracies estimates of the needed sample-sizes can be made for each cell.

The following remarks are based on the analysis developed by Dr. Julius Lieblein of TAD which was, in turn, derived from the above sampling and utilization factors.

*It is assumed here that the required anthropometric dimensions with the largest natural variabilities are equivalent to those that determine a cell's boundaries.

Assume a random sample is taken from the population within a compartment or cell. For illustration purposes let the cell be defined as: Juvenile, Male, "Slim", stature between 50" and 51".

Let n = size of the sample drawn from the cell;

h = cell interval or width (here h takes the value 1", 1-1/2" or 2");

k = number of standard deviations of the estimate of the mean for the sample n. k defines the confidence interval associated with the estimated mean

Thus:

k	Confidence
1	.68
2	.95
3	.99

T = Tolerance or margin for sampling error for the given confidence, T takes the (Aubrey Jay's) value of 1/8".

Thus within our example cell n should be such that the estimated average arm length, say, of the cell sample should not be more than 1/8" from the true mean of the cell population, and that the confidence of this contention should be, say, .95 ($k = 2$) or .99 ($k = 3$).

The required sample size, n, is obtained as follows:

$$T = k\sigma_{\bar{x}} = k\sigma_x \; / \; n = k\,(h/\sqrt{12})/\sqrt{n}, \qquad (1)$$

Where the variable body dimension is assumed to be uniformly distributed within the small (1" → 2") interval (i.e., $\sigma_x = h/\sqrt{12}$). Solving Equation (1) for n, gives $n = k^2 h^2/12T^2$. Taking $k = 2$, $T = 1/8"$ and letting h assume each of its three possible values--1", 1-1/2" or 2" gives: $n = 22$ ($h = 1"$); $n = 48$ ($h = 1\text{-}1/2"$); and $n = 86$ ($h = 2"$).

The total sample size for each compartment, based on the factors given earlier in this Appendix are tabled below;

Age Block	Sex	Number of Cells	Minimum and Maximum Estimated Sample Sizes(n)
Children	Unisex	22(h=1")/44(h=1")	484 / 968
Juveniles	Male	60(h=2")/114(h=1")	5160 / 2508
	Female	60(h=2")/114(h=1")	5160 / 2508
Adults	Male	27(h=2")/85(h=1")	2322 / 1870
	Female	39(h=2")/85(h=1-1/2")	3354 / 4080

The minimum and maximum estimated required overall sample sizes are 10,724 and 17,690, respectively. Thus a reasonably distributed (age-wise) sample of about 21,000 subjects should produce the required mean dimension for all cells, with the desired accuracies and each at a confidence exceeding 95%.

APPENDIX B

Anthropometric Survey Proposal Submitted by Fels Research Institute

APPENDIX B

Anthropometric Survey Proposal Submitted by Fels Research Institute

THE NEED FOR THE SURVEY

Every industry that manufactures clothing or equipment for use by the public needs reliable body size data. Yet there has never been a comprehensive anthropometric survey of the American public - male and female, adults and children.

Body size is known to change with age during life, and from generation to generation. Between 1950 and 1967, for example, U.S. Air Force personnel increased in stature about 0.7 inches and about 10 pounds in weight, on the average. Such large changes in the average for a large group, indicative of unknown changes in the total population, are obviously important to manufacturers of clothes, vehicles, and other equipment worn or used by people.

It is a thoroughly established fact that only with reliable, comprehensive anthropometric data can manufacturers achieve the best fit of clothing or equipment to the users, with the least material, and at the lowest cost.

Faulty sizes are costly to the clothing industry (causing rejection of garments and waste of labor and materials). In vehicles, proper design, location, and adjustability of seats with respect to controls improves comfort and promotes safety. These are the basic reasons why it is important to survey body size in the present population.

SUGGESTED PLAN

1. Send 2-3 vans around the U.S. to pre-selected locations chosen by The Bureau of the Census to obtain a scientifically random sample. The vans would contain all the measuring equipment needed for the survey.

2. As many dimensions as possible would be taken semi-automatically by specially-procured equipment, with automatic data recording and processing.

3. A sample of about 20,000 would be sought because of the great diversity of American physical types; Alaska and Hawaii would be included. Adequate samples of Caucasians (who vary by region), Negroes, Orientals, Chicanos, American Indians, Eskimos and Hawaiians would be obtained, for both sexes and all ages from 2 to 80 years.

4. Primarily the data would provide means, standard deviations, ranges, coefficients of variation, and selected percentiles from the 1st to the 99th. Scattergrams could be provided. The published data would refer to the total population and major sub-sets.

5. The proposed dimensions are listed below, with illustrations showing body locations. In general, the length, breadth, thickness and circumference of each body segment would be obtained, plus many special dimensions (see visual index).

6. Although most of the data would be gathered semi-automatically, some would have to be taken by hand. To reduce the labor and time expended, and increase the amount of information obtainable, stereo-photographic methods have been developed that provide highly accurate whole body contour maps. These early attempts have been extended greatly by the Biostereometric Laboratory of Baylor University; therefore an additional biostereometric effort is proposed. Such a method not only greatly reduces subject time, but yields full dimensional knowledge of any part of the body of the subject. The photographic images can be remeasured when new information is desired, which is not possible with hand methods - you can't go back to your sample for new dimensions. Hand methods do work - they have been proven feasible on mass samples; and from laboratory results it is considered that stereo methods may well supplant hand methods for future mass sampling.

ESTIMATED TIME REQUIRED

1.	Technical planning (after funding)	1.5 - 2 years
2.	Data gathering	2 years
3.	Data reduction	1 year
4.	Reporting - perhaps in two stages	
	a. mimeograph publication of base data for those who know how to use them.	1 year
	b. formal publication of methods and other information for those who do not know how to use them.	1 year
	Total, about	7 years

ESTIMATED COSTS

	OPERATIONAL PERSONNEL	Salary	1 yr.	2 yr.	7 yr.	Total
1.	Director (1)	$20,000			$140,000	$140,000
	Ass't. Director (1)	18,000			126,000	126,000
	Anthropometrists (4)	9,000		72,000		72,000
	Advance man (1)	15,000		30,000		30,000
	Advance ass't. (1)	8,000		16,000		16,000
	Repair man (1)	10,000		20,000		20,000
	Van drivers (contract)		15,000			15,000
						$419,000

2. MEASURING EQUIPMENT (all with automatic data recording)

Hands and feet	10,000	
Body lengths	20,000	
Body breadths, depths	20,000	
Circumferences	10,000	
Centers-of-gravity (adult)	20,000	
Centers-of-gravity (children)	15,000	
Seated dimensions	15,000	
Anthropometric instruments	1,000	111,000

3.	Rolling stock either (1 trailer van, expansible @ 35,000; or) (3 trailer vans, @ 8,000 with "air-ride")	35,000
	Equipment installation	20,000
	Insurance	3,000
4.	Punch cards, tape, etc. (20,000 x 10 = 200,000 cards; = $300.) (tape - 700.)	1,000
5.	Per diem (8 persons x 365 x 2 x $25.00 = $146,000)	146,000
6.	Transportation (changing supervisiors, visit vans, etc.)	6,000
7.	Office costs	
	Computer (data reduction)	60,000
	Allowance for FICA & Major Medical	38,250
	Secretarial @ 8,000	56,000
	Overhead (at 65% of salaries & wages) approx.	308,750

8. Clothing (briefs for men, leotards for women, @ 2.00 each $ [illegible]0,000

9. Possible payment (10.00 per person) 200,000

10. Publication

Mimeograph (300 pages, 500 copies), about $5,000

Permanent (paperback, 5,000 copies, about $2.00 each $10,000)

	15,000
Total, standard anthropometry	$1,449,000

11. Biostereometric operations,

88 dimensions; $200,000/yr. x 4 years	800,000
Total, combined programs	$2,249,000

APPENDIX C

Anthropometric Survey Proposal Submitted by Texas Institute for Rehabilitation and Research, Baylor College of Medicine

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Anthropometric Survey Proposal Submitted by Texas Institute for Rehabilitation and Research, Baylor College of Medicine

INTRODUCTION

There is a serious lack of comprehensive information about the body shapes and sizes of today's US population. This viewpoint is shared by the fifty leading designers, engineers, quality control experts and officials of commercial, government and professional organizations, who attended a meeting on the subject in Washington DC, October 22-23, 1973. Listed below are some of the major industries represented at the meeting along with specific products for which nationally representative body measurements are badly needed.

1. Apparel (designers, pattern companies, manufacturers, wholesalers, mail order and other retailers)--all types of clothing.

2. Personal protective equipment--headgear, respirators, glasses, gloves, footwear and various types of body armor.

3. Sports and recreation--toys, playground equipment, safety items for football and other sports.

4. Transportation--bicycles, tricycles, motorcycles, cars, aircraft and mass transit systems.

5. Furniture and interior design--chairs, tables, bedding, office equipment, and work stations.

6. Architecture--doors, doorways, hallways, stairs and ramps.

7. Household products--kitchen and other home appliances.

8. Occupational safety--military, law enforcement, construction and mining equipment.

9. Prosthetics--modular design of artificial limbs.

Several of the participants pointed out major deficiencies in previous anthropometric surveys. These included:

1. Limited scope--confined to a small selection of academically-interesting, linear measures, which are too limited to meet important industry needs.

2. Unsuitable format--data presented in a format which does little to encourage wide usage at early stages in the product design process.

3. Limited potential for extrapolation--traditional anthropometric permutations of lengths, breadths and circumferences leave many gaps in the quantification of human body form and dimensions not included in the original selection can rarely be recovered.

MAJOR AIMS OF THE PROPOSAL

Representatives of the apparel industry were particularly outspoken in expressing the above concerns. For this reason and because the principal investigator has had a special interest in this area for several years, satisfying the body measurement needs of the apparel industry is the major objective of the present proposal. Furthermore, by satisfying the broad-ranging requirements of the clothing industry we can, simultaneously, generate all the necessary data to produce computerized solutions for many other important body measurement problems in industry and medicine. These results can now be achieved by combining biostereometrics, a new approach to the measurement of body form, with the remarkable versatility of computer modelling (numerical and graphic) techniques. The apparel industry problem will be discussed in Part I of the proposal. Applications of the resulting data to other areas will be treated in Part II.

THE APPAREL INDUSTRY PROBLEM

The apparel industry has invested considerable sums of money in such new tools as (i) automatic cutting of fabrics, which promotes greater efficiency in the use of manpower and materials; (ii) interactive computer graphics techniques, which are enhancing the performance of drafting and styling operations, and (iii) the use of computerized point of sale registers to streamline retailing transactions. But, unfortunately, as long as there is a lack of pertinent information about the body shapes and sizes which comprise the US population, the real potential of these and other technological advances can never be realized. For example, little can be done to further upgrade matters of sizing, grading, patterning and fitting. At present, the garment industry has to rely on sizing dimensions which have been adapted to modern needs largely through a process of trial and error. This information gap results in higher costs at all stages in clothing production.

1. The Solution

Biostereometrics is scientifically defined as "the spatial and spatio-temporal analysis of biological form and function based on principles of analytic geometry." Putting it simply, biostereometrics is a modern, three-dimensional approach to the measurement of body form. The same basic principles which have been applied successfully in the earth sciences for many years, can now be used to measure 3-D body geometry. Various three-dimensional "form sensors" have been touted recently. They range from simple mechanical types to more exotic photo- and electro-optical varieties (e.g., lasers, holographic and related interferometric devices), but continuing research in this area has assured us that specially-designed stereometric cameras constitute the most versatile, reliable and otherwise appropriate 3-D sensors for body measurement surveys. The next few paragraphs will outline how the records (stereometric images) are reduced to digital coordinate form for computer analysis and storage. A flow diagram of the entire process is shown in Fig. 1 (a and b).

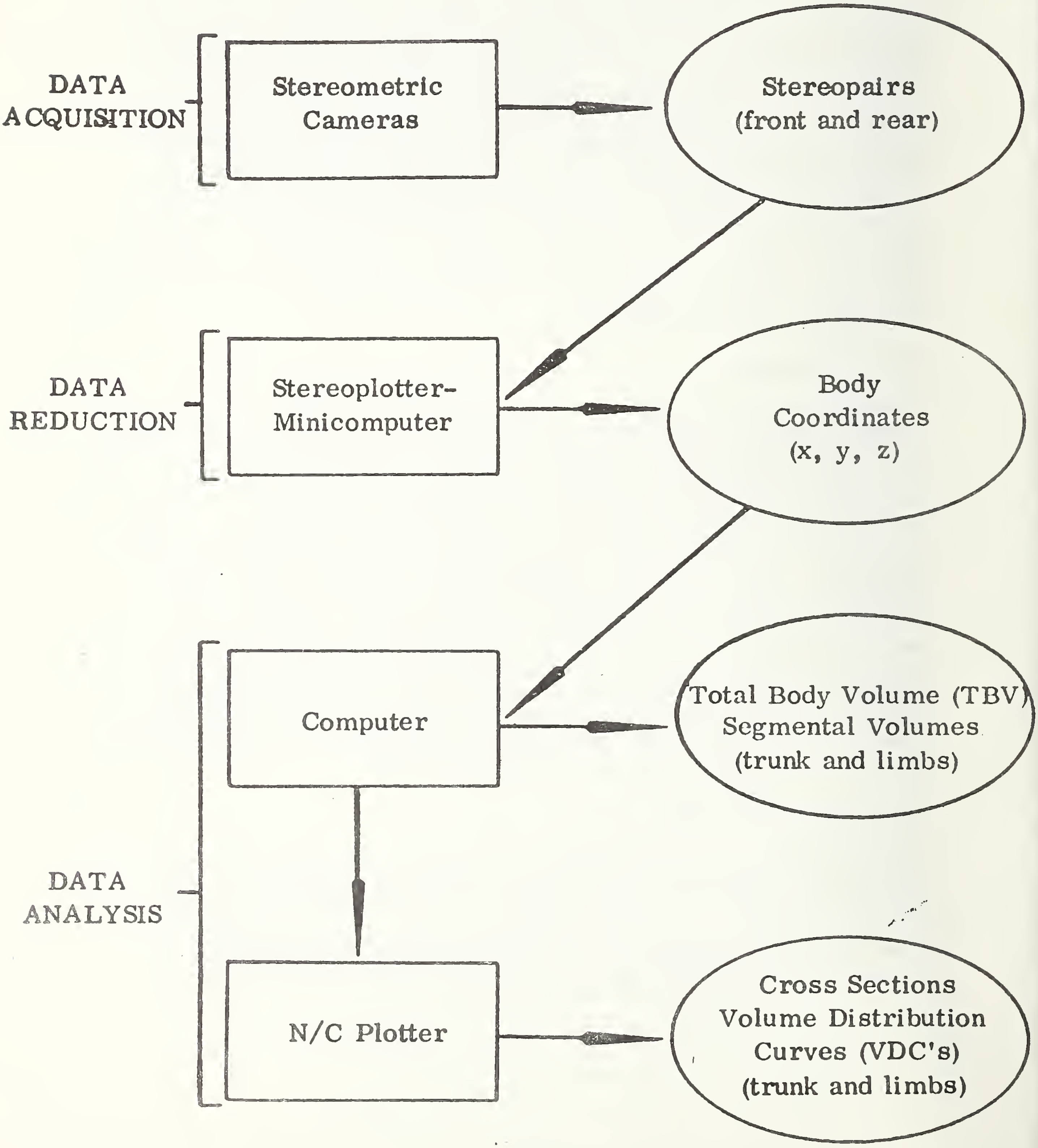
1.1 Data Acquisition

To quantify the human body form (or the form of a body part) we start with the assumption that the object surface is composed of an infinite number of points. By locating enough of these points in three-dimensional space, using Cartesian (x,y,z) or other coordinates, we can quantify the three-dimensional form of any body part which is accessible to stereometric sensing. As mentioned above, there are

FIGURE 1a

STEREOMETRIC MEASUREMENT OF BODY FORM

Process Chart



PROCESS CHART : INSTRUMENTATION

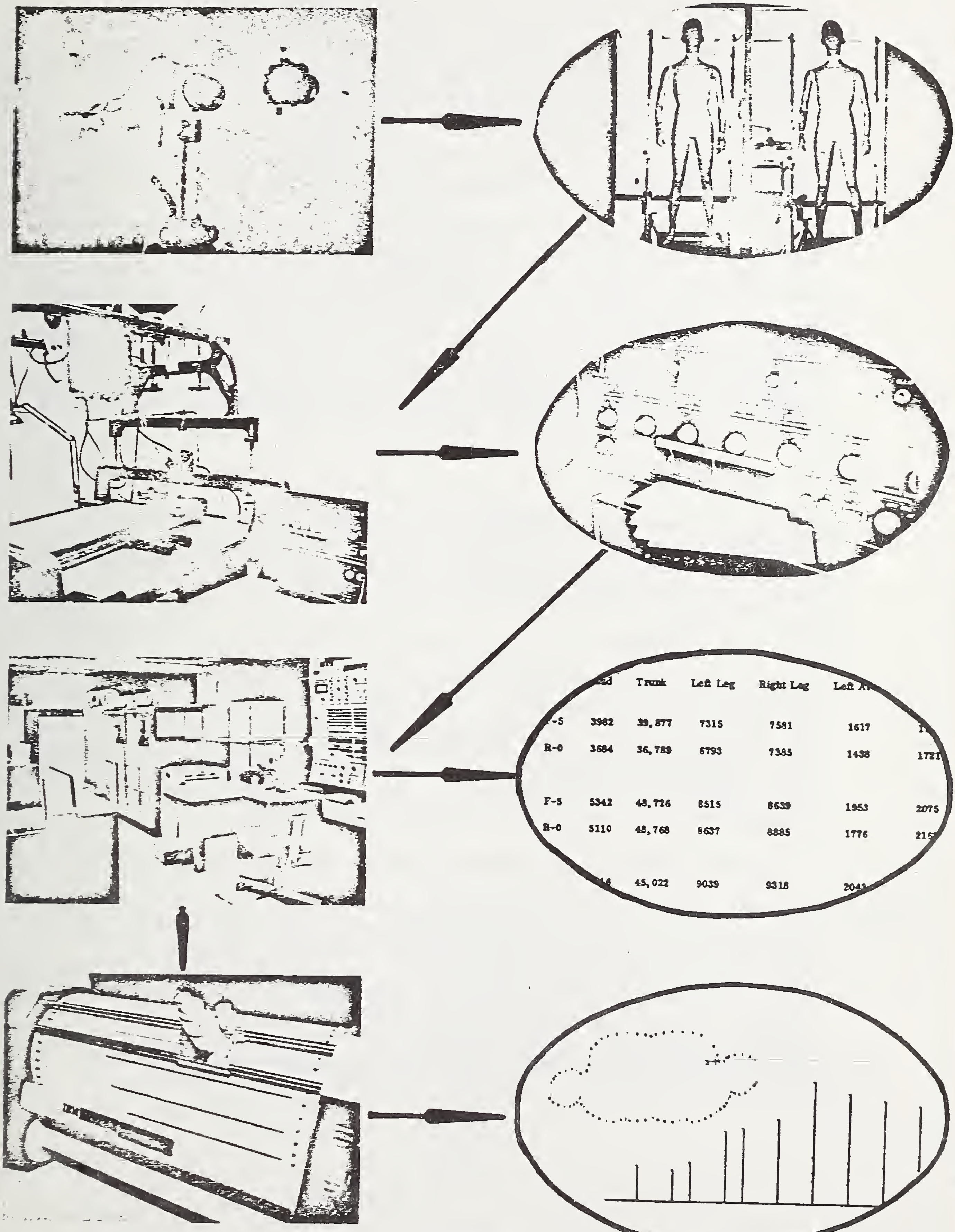


FIGURE 1b

various types of stereometric body sensors, but we prefer to use specially-designed stereometric cameras on the grounds of their reliability, versatility, durability, tolerance of varied environmental conditions, metric quality, portability and convenience, along with the fact that we have built up extensive experience in using this type of equipment over the last seven years.

The arrangement of stereometric cameras and reference/calibration stands for whole body measurement is shown in Fig. 2.

The body form is instantly recorded in the form of two pairs of overlapping stereophotographs. The resulting three-dimensional optical model is a permanent, easily-stored substitute for the body itself--a precise model which can be measured in great detail without taxing the patience of the subject since his or her presence is no longer required. An attractive feature of this approach for survey purposes is the portability of the equipment--one of our laboratory units has travelled over 50,000 miles for use in measuring Apollo and Skylab astronauts and a wide variety of medical and governmental (for DOT, Army and Air Force, among others) projects.

1.2 Data Reduction

The three-dimensional coordinates of a network of points (suitably distributed over the body surface) are read off the optical model using automatic and semi-automatic stereoplotting procedures. A modern stereoplotting instrument is shown in Fig. 3.

1.3 Data Analysis

Computer programs have been developed to provide such information as body cross-sections (as well as body girths) from head to foot, segmental and total body volumes, and volume distribution curves showing how the body volume or the volume of a body part is distributed, together with a wide range of biomechanical data. These data outputs are in addition to the conventional type of linear anthropometric measures taken between selected anatomical landmarks.

2. Specific Needs of the Apparel Industry and How They Will Be Met

The body measurement needs of the apparel industry are both immediate and long-term. In the immediate category are body measurements representative of the current US population which are compatible (in type, scope and format) with prevailing methods of styling, designing, drafting, grading, retailing and related operations. For obvious reasons, it would be inadvisable to generate unorthodox data or to use unfamiliar formats which the apparel industry cannot put to immediate use. At the same time, we must consider what the availability of comprehensive, computer-compatible, three-dimensional

FIGURE 2

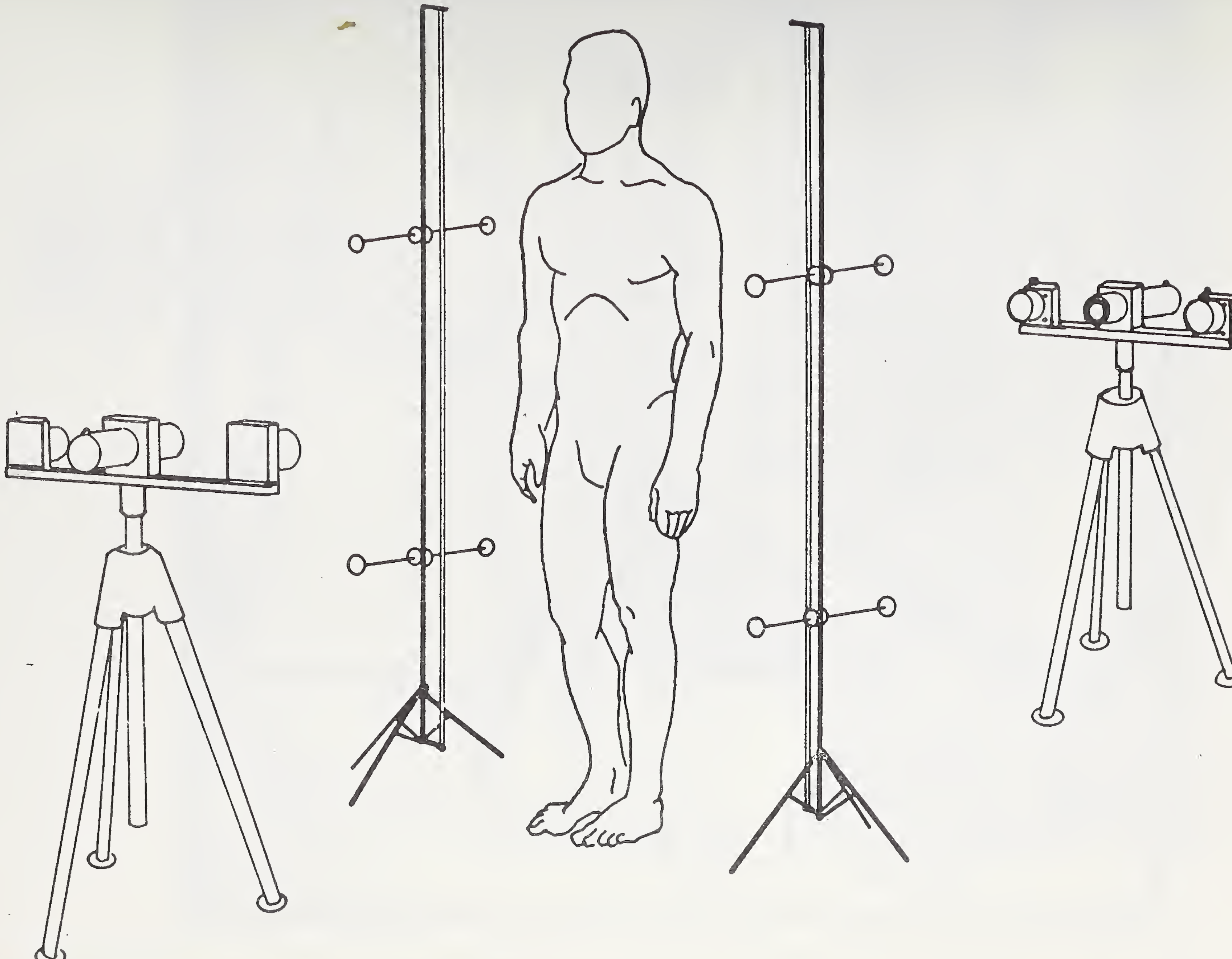
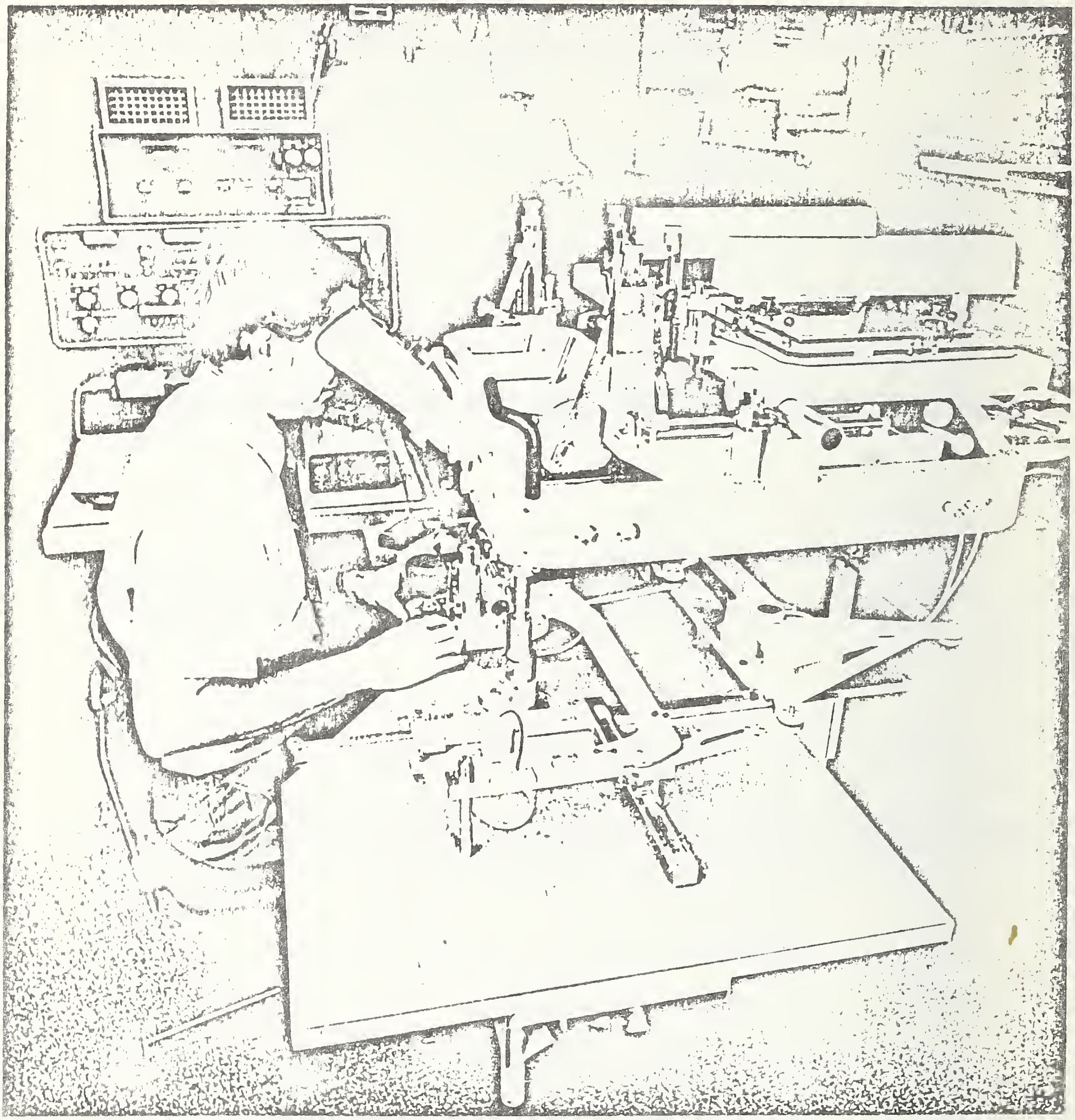


FIGURE 3



body data for the US population will mean in the future and how this information can be integrated into modern manufacturing and marketing plans. The fact that biostereometrics can accommodate both short-term and long-term objectives of the apparel industry is an appealing consideration. These matters are discussed in more detail below.

2.1 Short-Term Needs - Methodology

A national body measurement survey will be undertaken using biostereometric methods. Logistical details of the survey are now being developed. Suffice it to say here that the resources of the Bureau of the Census will be used to locate and identify a sample of approximately ten-thousand subjects which is representative of the US population with respect to age, sex, race, socio-economic and other pertinent variables. The sampling plan is expected to yield about 40-50 geographical population units. In each location, the measurement station will be housed in or at a medical center, to provide the kind of clinical setting most conducive to subject cooperation.

2.2 Specific Dimensions to be Measured

Each body form will be quantified in three dimensions using a network of data points distributed over the body surface. Thus the body geometry will be entered into the computer as a set of three-dimensional digital coordinates. The location of specific anatomical landmarks or other designated body landmarks will be included in the coordinate data set. Thus, certain dimensions in addition to those read directly off the optical-model will be calculated from the body geometry stored in the computer.

Body measurements known to be of special interest to the apparel industry include the following:[1]

<u>Vertical Measurements</u>

1. Total height
2. Cervical height
3. Waist height
4. Hip height
5. Hip-seat
6. Crotch height
7. Knee height
8. Calf height
9. Ankle height

<u>Circumference</u>

10. Mid forehead
11. Mid neck
12. Chest/bust
13. Rib cage

---

[1] Recently supplemented with a list of suggested body measurements agreed upon by the Sizing Sub-Committee of the MOAA.

14. Waist
15. High hip
16. Hip seat
17. Thigh
18. Mid thigh
19. Knee
20. Ankle
22. Upper arm
23. Elbow
24. Wrist

Widths

25. Across shoulder
26. Across back
27. Across chest

Lengths

28. Shoulder
29. Arm length
30. Forearm
31. Back waist
32. Front waist
33. Strap

Angles and Curvatures in Degrees

34. Shoulder slope, left
35. Shoulder slope, right
36. Shoulder blade at apex

Most, if not all, of these dimensions can be read directly off the 3-D optical model; a special computer program will be written to obtain the remaining dimensions from the computer-stored model, as outlined above and discussed in more detail below.

The ultimate selection of body measurements for apparel industry purposes will not be determined until after further discussions with responsible industry representatives. The above list does, however, represent a comprehensive permutation which, if accepted, would provide more than enough new information to justify the survey. Further discussions will be undertaken with apparel industry representatives to ensure that a wise and refined selection is arrived.

TABLE I

COMPARISON BETWEEN CONVENTIONAL ANTHROPOMETRIC AND BIOSTEREOMETRIC BODY MEASUREMENT CAPABILITIES

	Measurement Capabilities	Conventional	Biostereometric
1.	Diameters	Yes	Yes
2.	Surface Arcs	No	Yes
3.	Circumferences	Yes	Yes
4.	Cross-Sectional Shapes	No	Yes
5.	Slopes	No	Yes
6.	Whole Body Surface Area	No	Yes
7.	Body Part Surface Areas	No	Yes
8.	Whole Body Volume	No	Yes
9.	Whole Body Volume Distribution	No	Yes
10.	Body Part Volumes	No	Yes
11.	Body Part Volume Distribution	No	Yes
12.	Comprehensive 3-D Body Geometry	No	Yes
13.	Rapid Data Acquisition	No	Yes
14.	Re-Examination Without Subject	No	Yes
15.	Computer Modelling Potential	Limited	Extensive

PART III

BUDGET

The figures given in Tables II and III are current best estimates. Further discussions with the clothing industry representatives will be necessary to clarify finer points concerning acquisition of the 142 measurements suggested by the Sizing Sub-Committee of the Mail Order Association of America (11-5-73). Final selection of digital data coverage of each body form will be based on what constitutes "desired detail and accuracy." This will guarantee that the ultimate data capture is suitably comprehensive and, at the same time, cost-effective.

Table II shows the distribution and rate of expenditures based on a sample of 10,000 subjects. Table III contains itemized details of personnel costs for the entire project period. It is important to relate the budget figures to the task/time reduction rate information given in Tables IV and V. Data acquisition is expected to take a little over one year but data reduction will be undertaken concurrently and the mid-point (5,000 cases) in data reduction will be reached shortly after data acquisition is completed. Since the first half of the sample will contain more than half the ultimate information content of the total data capture, much valuable information will become available during the initial 12-15 months of the measuring process. In short, although the "tooling up" period cannot be compressed readily due to the complex logistics involved, once the project is underway, substantial population information will be available within a short time. In the future, sub-sampling procedures (after the original survey is completed) will allow the population data to be updated within an even shorter period (3-6 months or less as the process is further refined).

TABLE II

DISTRIBUTION/RATE OF EXPENDITURES PROPOSAL (IN THOUSANDS) FOR 10,000 SUBJECTS

		0 yr – 1 yr	1 yr – 2 yr	2 yr – 3 yr	3 yr – 4 yr	
ADMINISTRATION	Labor	31	33.5	36.2	39.1	139.8
	Materials	5	7	9	5	26.0
RESEARCH	Labor	100	110	118.8	128.3	457.1
	Materials	75	75	35	35	220.0
PHOTOGRAPHY (4 units)	Labor		102	86		188.0
	Materials	95	117.3	142.7		355.0
STEREOPLOTTING	Labor		122	192	222	536.0
	Materials	125	125			250.0
COMPUTING	Labor	16	17.3	18.7	20	72.0
	Materials		7	8		15.0
OVERHEAD	TIRR	46.8	122.5	143.8	130.4	443.5
	Building Rent	12	12			24.0
SAMPLING SUBCONTRACT		75	85	95		255.0
SUBTOTALS		580.8	935.6	885.2	579.8	2981.4
SUMMARY TOTALS						
	Labor	147.0	384.8	451.7	409.4	1392.9
	Materials	300.0	331.3	194.7	40.0	866.0
	Sample	75.0	85.0	95.0		255.0
	Overhead	58.8	134.5	143.8	130.4	467.5
SUBTOTALS		580.8	935.6	885.2	579.8	2981.4

GRAND TOTAL 2981.4

TABLE III

BUDGET IN THOUSANDS
FOR
10,000 SUBJECTS

	Time	$ in Thousands	Totals
ADMINISTRATION			
Principal Investigator	25%		
Secretary	100%		
Administrative Assistant	100%		
Maintenance Man	100%	139.8	
Supplies and Travel		26.0	
			165.8
RESEARCH			
3 Research Associates	100%		
3 Research Assistants	100%		
Machinist	100%	457.1	
Materials		220.0	
			677.1
PHOTOGRAPHY			
8 Photographers	100%		
4 Administrative Assistants	100%	188.0	
Materials and Equipment		355.0	
			543.0
STEREOPLOTTING			
20 Plotter Operators	100%		
2 Supervisors	100%		
1 Data Processor	100%	536.0	
10 Plotting Systems		250.0	
			786.0
COMPUTING			
Systems Programmer	100%	72.0	
Paper and Record Materials		15.0	
			87.0

TABLE III (Cont'd)

	Time	$ in Thousands	Totals
RENTAL OF ADDITIONAL SPACE	100%	24.0	24.0
OVERHEAD			
TIRR @ 31.84% of salaries		443.5	443.5
SAMPLE SUBCONTRACT		255.0	255.0
	GRAND TOTAL		2981.4

TABLE IV

TASK/TIME PROPOSAL FOR 10,000 SUBJECTS

ADMINISTRATION
General

SAMPLING
Draw and Provide Sample

RESEARCH
Design, Build System and General Tool Up

COMPUTER
Develop Controlling Software for Plotting System

PLOTTING
Set Up New System and Train Operators

PHOTOGRAPHY
Train Photographic Teams in Data Acquisition Procedures

PHOTOGRAPHY
Data Acquisition

PLOTTING
Data Reduction

COMPUTER
Data Production, Controlling Software Maintenance

RESEARCH
Refine and Increase Throughput Capabilities

SAMPLING
Documentation of Sample

ADMINISTRATION
Interim and Final Reports

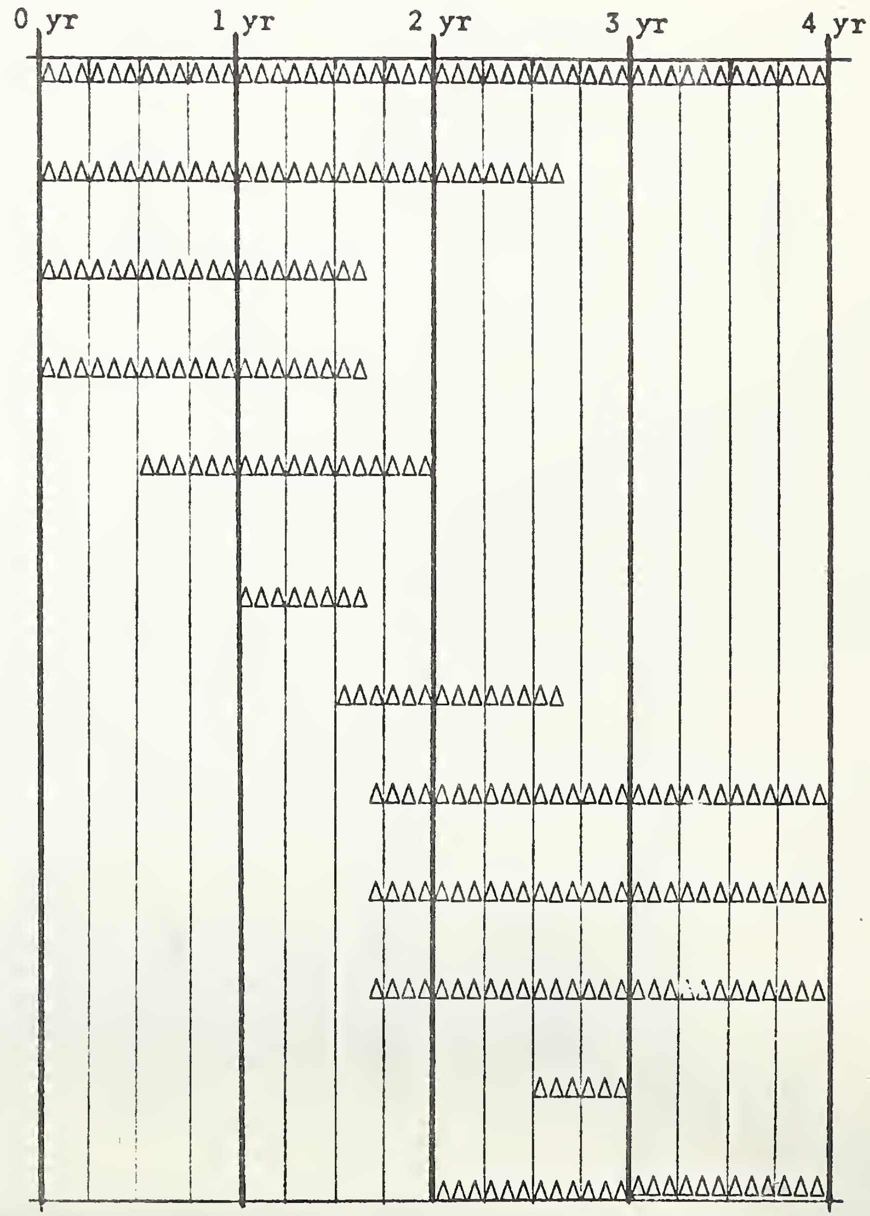
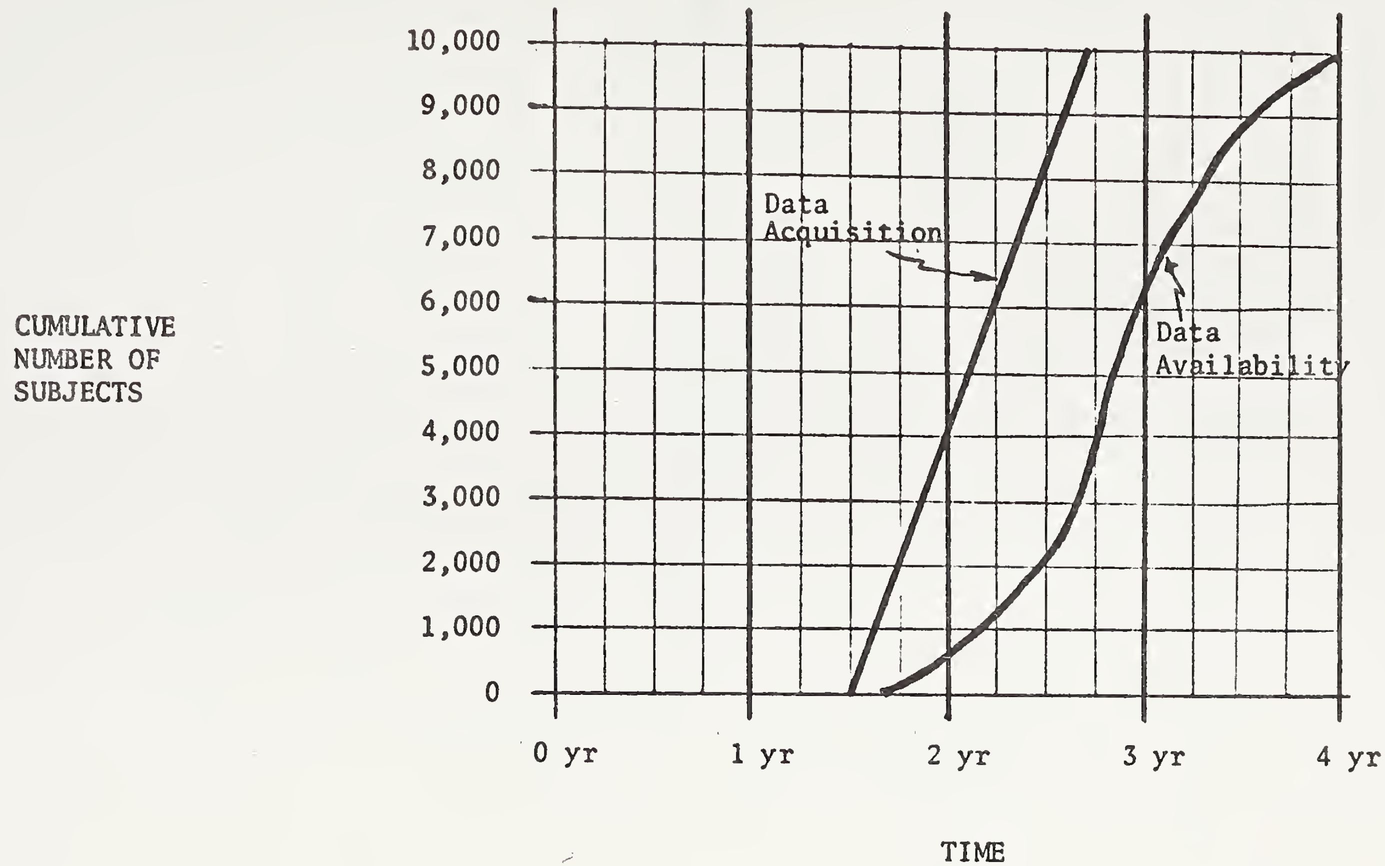


TABLE V

PRODUCTION RATE



APPENDIX D

Contacts Made in the Course of this TAD Survey

APPENDIX D

Contacts Made

Agency	Contact	Contact Mode(s)
NBS	Eric Swarthe (411.01)	Person/Tele
	C.W. Devereux (401.03)	Person/Tele
	Dr. J. Lieblein (431.00)	Person/Tele
TIRR	Dr. R.E. Herron	Person/Tele/Mail
	Jaimie Cuzzi	Person/Tele
	Dan Goulet	Person/Tele
DHEW/NCHS	Garrie J. Losee (Deputy Chief)	Tele
	Arthur MacDowell	Person/Tele
	Charles Galesse	Tele
	Henry Miller	Tele
Fels	Ed Hertzberg	Tele
	Dr. Alex Roche	Tele
NIH	Dr. Sam Greenhouse (Child Health & Human Development)	Tele
	Dr. Steve Read	Tele
	Dr. Leo Von Euler (Behavioral Science)	Tele
	Dr. William Taylor (Behavioral Science)	Tele
Census	Dan B. Levine (Office of Associate Director for Demographic Fields)	Tele
NGS	Bill Teyman	Tele
	? Starr	Tele
NSF-NRC		Tele
Armour Food	Dr. Herring	Tele
Del Foster Company San Antonio, Texas	Del Foster	Tele
Danko Arlington, Inc.	Joe Danko	Tele
J.C. Penneys (NY)	Aubrey Jay	Tele/Mail
"After 6"	Richard Grassi	Tele
International Assoc. of Clothing Designers	H.L. Feiner	Tele/Mail

APPENDIX E

Factors Common to All Pilot Studies

APPENDIX E

Factors Common to All Pilot Studies

Irrelevant of which scenario is selected for the anthropometric study, a pilot project will be required. Although a few of the aims of the pilot study associated with each scenario are unique to that proposal, a commonality of aims is more the rule. For convenience, those commonalities contained within the three (Scenario) pilot studies are presented below. Features unique to each project are given in the respective sections.

1. The pilot study should involve the examination of from 500 to 1000 subjects. These subjects need not be representative of any population but should include both sexes and all age groups.
2. This study should begin as soon as possible so that fundamental objections that NCHS might have to including the main anthropometric study in its '76 survey are overcome by early 1975 (at which time NCHS must firm up its survey plans). Problems of a secondary nature, as well as training of field workers, etc., can be dealt with during the 1975 calendar year. Aspects of this study can run beyond the inception of the principal survey.
3. The pilot study can be restricted to one site. Although much of the examination can be done at the home base of the group performing the study, some simulated field work should be included. Additional sites could be used but only as they relate to specific study aims.
4. The uniforms worn by all segments of the sampled population must be designed to optimize data obtention capability and minimize potential subject embarassment. In particular, questions relating to measurements involving the hair, breasts, crotch and feet

must be dealt with. Anatomical landmarks, as well as premarked points must be accessible. These questions are undoubtably more relevant to those measurements based on photogrammetry.

The time block required by each subject for anthropometric measurements should be as short as is feasible within the framework of obtaining the required set of anthropometric measurements and/or stereo-photographs. This is especially true In Scenario B where standard anthropometric methods will be the principal means of obtaining required dimensions. Alternatively, with regards to the use of photogrammetry (as the principal means of obtaining the basic data), it is imperative to limit the number of stereo-pair photos that must be (taken and) analyzed.

In all cases it is desirable to limit, as much as is feasible, the number of poses required of each subject.

5. With regard to the above considerations it is necessary to determine what highly accurate and reliable correlations exist between the various body dimensions and poses? Thus, if most required seated dimensions can be accurately and consistently predicted, subject and analyst time can be saved at little overall cost to data reliability. Again, what skin-fold measurements might be so well correlated with, say, girth dimensions as to eliminate the necessity of their direct measurement?

6. (Related to #5) How different are right and left limb measurements? If there are significant differences it may be desirable to investigate these within the principal survey. If the differences are found to be small, or can be reliably correlated with each

other and with claimed "handedness," then future measurement requirements can be adjusted accordingly.

7. In all cases, proposed methods of measurement involve novel aspects that must be resolved to everyone's satisfaction. All proposed scenarios require the development, production, testing and calibration of electro-mechanical or electro-optical devices. All scenarios also involve the development of substantial amounts of software (computer programs).

8. Accurate assessment of the time and cost of the principal survey should be possible once the pilot project has been completed.

9. In all cases NCHS might demand the inclusion of their staff as part of the anthropometric field team complement. Such a demand, however, would only add experience to the field team and, if NCHS bore the cost of such personnel, a reduction in (external) project cost could result.

10. Adaptation of selected anthropometric techniques and instrumentation to very young and elderely subjects.

APPENDIX F

Costing of Selected Scenarios

APPENDIX F

Costing of Selected Scenarios

The costs given in this Appendix represented estimated values. The limits associated with these costs represent crude estimates of 95% confidence limits. That is, it is felt that there is only 1 chance in 20 of these estimates being exceeded, under the assumed scenario.

Scenario A

Factor		Cost
Pilot Study Add'l Research	Here we use Herron's basic figures (Appendix C) for 3 Research Associates, 3 research assistants and a machinist. (Projects will last 1 year longer than Herron anticipates, but to a degree, this is compensated by a slightly smaller staff).	457 + 70 -150
	Materials required during pilot study.	220 ± 40
Personnel	Assume 2 field workers (possibly one male and one female) plus a supervisor for each of two field crews. These workers will be in the field for 3 years. A per diem rate of $30/day for 330 days/yr., is assumed for each of these. For remaining personnel a total annual per diem level of 50 days/yr. at $30/day is assumed. Remaining staff and office supplied are costed as follows.	

Type Worker	Annual Salary	# Year	% Time	Cost Factor	
Field (4)	10K	3.2	100%	128K	218 + 80
Field Sup (2)	14	3.2	100%	90	- 20
Principal Investigator	20	5.5	20%	22	
Secretary	8	5.5	100%	44	193 + 30
Administrative Assistant	14	5.5	100%	77	- 50
Maintenance	10	5	100%	50	
Office Supplies				20	20 ± 5
Travel*				10	10 ± 3
Per Diem*	$30x6x	3x	330d/yr		178 ± 30
Administrating Agency					
Administrator	25	7	100%	175	217 + 20
Secretary	8	7	75%	42	- 40
Travel*	-	7	--	25	25 ± 5
Final Computations Agency					
Secretary	8	2-1/2	50%	10	10 ± 3
Travel*	-	2-1/2	-	5	5 ± 2

*"Per diem entry is strictly for field workers. "Travel" estimates are for trips made by the various senior personnel. It is assumed that a realistic per diem rate for the period from 1974 through 1981 is $30.

Factor	Description	Cost
Basic Field Equipment	Need two stereo-pair, camera/strobe setups plus a backup setup per site. Joe Danko & Co. are developing this photogrammetric equipment. Each stereo-pair setup is estimated to cost $6K and should be ready by end of '74. Add one setup for research back at Houston.	42K + 15 - 3
	May use 2 frames into which cameras can be fit to create a fixed geometry. Need 3 rods within which to derive the focal plane and depth of field, at each site.	15 + 3 - 5
	Additional anthropometers are needed to measure height, skinfold, etc. Three special, adjustable chairs may be needed to obtain seated measurements (one per site plus a backup)	5 ± 2 1 ± 1
	Caps, gowns, feet covering, etc., for subjects. Assume about $2.50 cost per subject. Assume will need 21,000 + add'l 2,000 (subjects get to keep uniforms). Hopefully these uniforms will also "do" for NCHS.	58 + 5 - 10
	If photogrammetric and anthropometric equipment can't be contained in a NCHS van, two vans will be required. If two vans must be purchased for project will also need licences, gas, insurance and maintenance, snow tires, etc. I am assuming however, that NCHS will allow anthropometry group to utilize space in one or their 4 vans (per site).	0 + 90 - 0
	Need 2 processing units to develop (sheet) film on-site, plus two back-up units at Houston. Each unit costs - $1K. Assume duplicate* front and back stereo-pair pictures will be taken for each of 21,000 subjects and, in addition, will require 2500 test sets (at 4 sheets per test). At, say 15¢/sheet of film plus cost of darkroom equipment and mailing negatives back to Houston.	33 ± 7

*Although two sets of stereo-pair photos will be taken for each subject only one of these sets (the better of the two when possible) will be analyzed. The photos not analyzed will be stored and possibly be used for ancillary projects. It is assumed that each worker will work 250 days a year and be able to analyze -3 stereo-pair photos per day. Over a period of 3.2 years this comes to 250 x 20 x 3 x 3.2, or 48,000 photos. There will be 2 x 21,000 = 42,000 stereo-pairs from the main survey and the difference, 6000 stereo-pairs will come, in part, from pilot project photos and the remainder from reanalyses (error corrections).

Factor	Description	Cost
Stereo-Plotting Personnel	Will need 20 workers for 3.2 years to man two 10-man shifts/day during actual survey. These can be low level personnel at $7K/yr.	448 ± 150
	Also need two supervisors and one data-processor, each at 14K for 3.2 years.	134 + 20 - 5
Stereo-Plotting	Dell Foster Co., San Antonio, Texas will develop a phototype stereo-plotting system for developing Herron's stereo-pair negatives. This system will consist of (probably): A "Nova 1200", 24K core memory computer with 2.5 million word disk storage, including a write-on tape drive; and two stereo-plotters including: encoders, servo stepping motors, quantizers, etc.	
	Will need 8 additional stereo-plotting systems and, since one Nova 1200 can only drive two plotting systems, may need 8 plotters at - 15K each plus 4 more Nova 1200's at - 40K each. If a Nova 1200 proves capable of driving more than 2 plotting systems then the total number of Novas needed could drop to 3 or 4 (for now we assume total of 5 needed).	400 + 30 - 80
Space at TIRR	TIRR presently has an expansion wing under construction. It should be completed in about two years. If TIRR needs additional space before that time it will be necessary to lease this space. Since real push would actually come two years from now, I am halving Herron's value here.	12 ± 12
Initial Computations	For the first, say, 1-1/2 years of the actual survey the stereo-plotting system (described above) will produce only adjusted XYZ data. During this time the IBM 360/50 will perform the analyses that result in generation of holistic data for each subject analyzed. During this time it is anticipated that development of software that will permit the Nova's to generate the same holistic data will proceed. About 1/2 way into the survey (about 10,000 subjects analyzed) it is hoped that the Nova's by doing the holistic analyses during the night shift, will be able to supplant the IBM 360/50. Nevertheless, for the first - 10,000 subjects use of the IBM 360/50 will incurr, approximately, the following expenses: each person (front plus back) should use about 5 minutes of CPU time. Doubling this for corrections and changes in programming, etc. gives 100K minutes of CPU time. At - $175/hr (present rate of the Baylor computer is $160/hr) this gives $292K. Related I/O and other charges could add another 108K to this.	400 + 800 - 200

Factor	Description	Cost	
	A systems programmer would be required for 5-1/2 years here at a salary of about $15K/yr.	82K	+ 10 - 5
	His last year or so will be spent in developing a "population file" in preparation for further data analyses. This will probably be done on the IBM 360/50 and will cost an additional, say, 20K. It should be mentioned here that some useful body dimensions or parameters may be computed along with the holistic data - such as: body-segment-volumes, surface areas, center of masses, moments of inertia, etc.	20	+ 20 - 5
Final Computation	Remainder of required analyses could be done by TIRR or, alternatively, could be performed by elements within the supervising agency or could be contracted out. The following analyses are included in this project phase: (a) computation of requisite body dimensions (girth, lengths, etc.) from holistic coefficients (b) sorting of subjects according to selected variables (age block, sex, socio-economic group, race, region, occupation, etc.); and (c) statistical analyses (means of various dimensions within parametric groupings, standard deviations thereof, ranges, multivariate analyses, etc.). Step (a) might be performed by TIRR while (b) & (c) could be done elsewhere - the efficiency or inefficiency of this alternative is not clear. However, tentative analyses of early data should produce feedback that might make further analyses more efficient or accurate. A programmer will be needed to complete steps (a), (b), and (c). This project phase should last, say, 2 years. Assume a programmer salary of $14K/yr. A senior statistician will also be required (estimated salary - 22K/yr.) for, say, 3 years to outline computations and to follow them along.	94	± 20
	Computer costs to complete steps (a), (b), and (c) might run at ______________________________	350	±100
Document Printing	Printing of the final documents for overall dissemination is included here. (Renumeration to the project from the sale of these reports is possible.)	20	+ 20 - 5
Overhead	Overhead, assumed to run at 0.8 time personnel costs (independent of agency considered), is broken down by functional recipient group.		

Group	Overhead	
Initial Phase	$ 1226	$1226 {}^{+50}_{-700^*}$
Final Phase	83	$83 {}^{+15}_{-50^*}$
Administration	174	$174 {}^{+15}_{-30}$

A summary of the estimated cost factors, within a time frame matrix, is given in Figure 1.

---

* These large uncertainties have been assigned to the lower bounds of the overhead for the "Initial Phase" and "Final Phase" agencies due, principally, to the divergence between the overhead rate used (0.8), and that given by TIRR (0.32).

F .2 Scenario B

Factor	Description					Cost
Personnel (Administration and Field)	Fels Institute					
	Type	Annual Salary	No. Years	% Time	Cost Factor	
	Director	$20K*	7**	100%	140K	336K ± 50
	Ass't Dir.	20	7	100	140	
	Secretary	8	7	100	56	
	Field Staff:					
	Anthropometrists (6)	10	3.2	100	192	282 ± 30
	Supervisors (20	14	3.2	100	90	
	Per Diem***				238	238 ± 20
	Travel		7		20	40 ± 10
	Office Supplies		7		20	
	Administrating Agency					
	Administrator	25	7	100%	175	217 + 20 - 40
	Secretary	8	7	75%	42	
	Travel***	--	7	--	20	25 ± 50
Measuring Equipment	Fels equipment cost estimates are found in Appendix G. It appears that the quoted costs are four development plus delivery of a single proto-type of each device. This means, that an additional three of each type device will have to be added to cost. An exception here are the center of gravity chairs which are assumed too bulky to permit inclusion of back-up units in each field unit.					200 ± 50
	The cost of uniforms for the 21,000-plus subjects is assumed identical to that of Scenario A, except that here a headcap will not be required. This should reduce the per unit cost by about 25¢ (to $2.25 per subject).					52 + 5 - 10

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*This rather modest annual salary is all that Mr. Hertzberg claims he shall request over the duration of the project.

**A fusion of our basic scenario with that plan submitted by Fels would result in an eight year project. For consistency, however, an post-survey analysis/ documentation times are taken to be two years.

***"Per diem entry is strictly for field workers. "Travel" estimates are for trips made by various senior personnel. It is assumed that a realistic per diem rate for the period from 1974 through 1981 is $30.

Factor	Description	Cost
Computation Personnel	For both initial and final computations will require services of a computer programmer for about 5 years at - 14K/yr; a senior level statistician will be required for about 3-1/2 years at - 22K/yr.	147 ± 30
Initial Computations	Computer costs associated with statistical analysis of data obtained during pilot study.	5 ± 2
Final Computations	Computer (Data Reduction) costs. Here we assume costs to be equivalent to those estimated "Final Computation" costs given in Scenario A (See Section 4.2). Note however, that factor (a) ("Computation of requisite body dimensions... from holistic coefficients") is not required here.	100 + 70 - 30
Document Printing	See Section 4.2	20 + 20 - 5
Overhead	Overhead, assumed to run at .8 times personnel costs (independent of agency considered), is broken down by functional recipient group.	
	Group / Overhead	
	Administration 174	174 + 15 - 30
	Survey + Analysis 612	612 + 65 -120*

A summary of the estimated cost factors, within a time-frame matrix, is presented in Figure 2.

*This large uncertainty in the lower limit of the overhead for Fels is due, principally, to the divergence between the overhead rate used (0.8) and that given by Fels (0.65).

F.3 Scenario C

Since the costing for this scenario is quite similar to that for Scenario A, only the divergences will be presented below: Refer to Paragraph 4.2 for Scenario A cost factors.

Factor		
Personnel	In effect here, the "Field Supervisors" of Scenario A are replaced with anthropometrists supplied by Fels. The salary here is unchanged, however. Fels would supply a "principal investigator" (Ed Hertzberg) who would act, principally, as a consultant to the project. Ed would work actively during the initial as well as the final stages of the project. This, in effect, adds about three years of Ed's time at $20K/yr. and a 25% level of effort to the project.	16K $^{+8}_{-3}$
	Travel for Ed during first phase of project could add extra 3K to project. It is suggested that TIRR retain responsibility for the conversion of their holistic data into its body dimension from (Step (a), "Final Computations" factor, Section 4.2).	3 ± 5
Overhead	At 0.8 of Fel's salaries	13 ± 5

APPENDIX G

List of Requested Dimensions Developed by the Sizing Subcommittee of the Mail Order Association of America

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List of Requested Dimensions Developed by the Sizing Subcommittee of the Mail Order Association of America

1. Stature-Total Height
2. Shoulder Point Height
3. Suprasternale Height
4. Nipple Height
5. Waist Height(Narrowest point related to a vertebrae number)
6. Wrist Height
7. Bottom of Arm Scye Height
8. Neck Point Height(where shoulder joins the neck at the highest point)
9. Clutgal Furrow Height
10. Middle Finger Tip Height
11. Hip Height(at widest point)
12. Hip Bone Height
13. Elbow Height
14. Cervicale Height
15. Top of Knee Height
16. Mid Knee Height
17. Bottom of Knee Height
18. Crotch Height(from apex of body crotch round)
19. Chest Depth
20. Waist Depth(measured at #5)
21. Buttock Depth
22. Chest Breadth
23. Back Breadth
24. Waist Breadth(measured at #5)
25. Hip Breadth
26. Hip Breadth Sitting
27. Under Arm Length(from bottom of arm scye to waist bone protusion)
28. Upper Arm Circumference Flexed
29. Upper Arm Circumference Flexed
29. Elbow Circumference Flexed
30. Half Cross Back(spine to back scye)
31. Arm Length to Elbow(spine to elbow with arm bent and held at right angles to body)
32. Arm Length to Wrist(same position as 31)
33. Waist(Measured at #5) to chair seat(subject sitting)
34. Posterior Neck Length
35. Back Waist Length(Measurement #5)
36. Total Crotch Length(Measurement #5)
37. Anterior Neck Length
38. Front Waist Length
39. Neck Base Circumference
40. Midneck Circumference
41. Scye Circumfrence
42. High Hip Circumference(at hip bone)
43. Hip Breadth(at hip bone)
44. Hip Depth(at hip bone)
45. Hip/Seat Circumference
46. Calf Circumference(state where)
47. Calf Height(state where)
48. Ankle Circumference(apex of ankle bone)
49. Ankle Height(botom of ankle bone)
50. Vertical trunk circumference(at point where neck joins shoulder)
51. Upper Arm Circumference(extended)
52. Elbow Circumference(extended)
53. Lower Arm Circumference(extended)
54. Wrist Circumference
55. Shoulder Length(from where neck joins shoulder to end of shoulder bone)
56. Over shoulder Circumference
57. Chest Circumference

58. Waist Circumference(measured at #5)
59. Upper Thigh Circumference(as close to where leg joins body as possible)
60. Mid Thigh(Midway between upper thigh and top of knee height)
61. Lower Thigh
62. Knee circumference(at bottom of knee height)
63. Upper Thigh Circumference Sitting(measurement #54)
63a. Mid Thigh Circumference Sitting
64. Hand Length
65. Palm Length
66. Hand Circumference around Thumb
67. Hand Breadth at Thumb
68. Hand Thickness at Knuckle
69. Hand Breadth at Knuckle
70. Finger Diameter 1st Finger(at knuckle)
71. Finger Diameter 2nd Finger(at knuckle)
72. Finger Diameter Middle Finger(at knuckle)
73. Finger Diameter Index Finger(at knuckle)
74. Thumb Diameter
75. Finger Length 1st Finger
76. Finger Length 2nd Finger
77. Finger Length Middle Finger
78. Finger Length Index Finger
79. Thumb Length
80. Hand Circumference(around knuckles)
81. Foot Length(heel to big toe)
82. Instep Length(heel to ball joint)
83. Foot Circumference(at ball Joint)
84. Foot Breadth(at ball joint)
85. Heel Width
86. Foot Length(heel to little toe)
87. Foot Circumference(at instep)
88.
89. Ear to Ear Breadth
90. Distance Between Eyes(point to point nearest nose)
91. Distance Between Eyes(point to point nearest the temple)
92. Head Breadth
93. Maximum Forehead Diameter
94. Cheek to Cheek Diameter
95. Top of Nose Breadth
96. Nose Width at Widest Point
97. Upper Lip Length
98. Lip Length
99. Cheek Bone to Cheek Bone Diameter
100. Total Ear Length
101. Ear Length
102. Head Length(front to back)
103. Bitragion-Submandibular Arc
104. Bitragion-Menton Arc
105. Bottom of Nose to Upper Lip Length
106. Length from Center of Eye to Bottom of Nose
107. Bitragion-Coronal Arc
108. Sagittal Arc
109. Head Circumference
110. Bitragion - Minimum Frontal Arc
111. Bitragion- Subnasal arc
112. Ear Protusion
113. Bitragion Posterior Arc
114. Maximum Head Diagonal from Menton
115. Head Diagonal: Nuchang to Pronasale
116. Top of Eye to Bottom of Chin Length

117. Rib Cage-Under Bust(where breasts join body) Circumference
118. Over Chest Circumference(at start of breasts)
119. Nipple to Nipple Width
120. Full Strap(from nipple to nipple around back of neck)
121. Neck Point to Nipple Length(where neck joins shoulder at highest point to nipple)
122. Neck Point to Center Front Waist(neck point see #121)
123. Cervicale to Center Front Waist Length
124. Scye Depth(subtract #7 from #2)
125. Neck Point to Front Waist(neck point is #121 over nipple straight down to waist)
126. Across Shoulder Arc Width
127. Across Shoulder Width
128. Apex of Stomach to Apex of Seat Depth
129. Armhole Depth(front to back)
130. Shoulder Slope in Degrees
131. Age
132. Weight
133. Plumb Line Position

134. Waist to Crotch Volume
135. Crotch to Knee Volume(one leg)
136. Knee to Ankle Volume(one leg)
137. Top to Bottom of Knee Volume(one knee)
138. Top to Bottom of Ankle Volume(one ankle)
139. Waist to Ankle Volume(all components)
140. Left Breast Volume
141. Right Breast Volume
142. Rib Cage Volume(#117)

APPENDIX H

Computation of Total Program Cost Confidence Limits

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Computation of Total Program Cost Confidence Limits

The cost associated with each selected scenario are detailed in Appendix F. Confidence Interval (CI) estimates were provided for each costing factor. These intervals are thought to approximate 95% CIs for each cost factor. These costs (X_i) and associated confidence limits, (CL_i) are tabled and summed in Figures 1 through 3. While it is a straightforward task to total the N expected costs the combination of factor costs to provide CI estimates for each scenario total program cost, in a statistically meaningful way, is more complex. This complexity stems principally from the unequal CLs placed on several factors (e.g., in Figure 1 "Initial Computations," Computer cost is estimated at $420K with a lower 95% ($2\sigma$) CL of $220K, but with an upper CL of $1220K). Estimating the average standard deviation for all factors to be $CI_i/4$ [i.e., assuming all cost factors to be normal (gaussian)!] leads to a CI symmetrically distributed about the expected total cost (X_{tot}). The approach used, while not statistically rigorous, does permit the CI to float with respect to X_{tot}. That is, if there are significant cost factors whose limits are substantially lopsided, then the approach used permits these imbalances to be reflected in the upper and lower CL estimates.

The technique applied is based on the observation that, for all scenarios examined, only one or two factors were both significant and lopsided in their CI placement about the estimated cost factor, X_i. Assume all cost factors are ordered so that the lopsided one(s) are placed last (in Nth and (N-1)th positions.) For the case of only one

lopsided factor, X_N (Scenario B, "Overhead, Fels'") compute the quantity

$$\Sigma_1 = \frac{1}{4} \sum_{i=1}^{N-1} (CI_i)^2. = \frac{1}{4} \sum_{i=1}^{N-1} (X_{iu} - X_{i\ell})^2$$

Now the upper and lower CLs of the Nth factor (X_{Nu}, $X_{N\ell}$) are combined with Σ_1 to give the CLs for X_{tot}; taking $X_{tot} = \sum_{i=1}^{N} X_i$, gives

$$CL_{upper}\ (X_{tot}) = X_{tot} + \sqrt{\Sigma_1 + X_{Nu}^2}$$, and

$$CL_{lower}\ (X_{tot}) = X_{tot} - \sqrt{\Sigma_1 + X_{N\ell}^2}$$

Note that the square root represents two standard deviations, and not one, since Σ_1, X_{Nu} and $X_{N\ell}$ all contain factors of $(2\sigma)^2$. The estimated CI for X_{tot} is, therefore, approximately a 95% CI.

Where two factors within one scenario require special handling (as is the case for Scenarios A and C ("Initial Computations, Computer" and "Overhead, Initial Phase") they were handled as follows: Assume the two lopsided and substantial set of limits to be: $X_{(N-1)u}$, $X_{(N-1)\ell}$ X_{Nu}, $X_{N\ell}$. Since, in the actual case, the skewness of both sets of CLs were in opposite directions let:

$$\Delta_u = [X_{(N-1)u} - X_{N-1}] >> [X_{N-1} - X_{(N-1)\ell}],$$

and

$$\Delta_\ell = (X_N - X_{N\ell}) >> (X_{Nu} - X_N).$$

for this case:

$$\Sigma_2 = \frac{1}{4} \sum_{k=1}^{N-2} (X_{ku} - X_{k\ell})^2,$$ and

$$CL_{upper}\ (X_{tot}) = X_{tot} + \sqrt{\Sigma_2 + \Delta_u^{\ 2} + \frac{1}{4}\ (X_{nu} - X_N)^2}$$

$$CL_{lower}\ (X_{tot}) = X_{tot} - \sqrt{\Sigma_2 + \Delta^2_{\ell} + \frac{1}{4}\ (X_{(N-1)u} - X_{N-1})^2}$$

Another complication arises since, in the above calculations, all factors are considered to be randomly distributed with respect to each other. This assumption does not hold for the "overhead" cost-factor since it is computed as 0.8x the salary cost. This problem is handled by:

1. Computing the upper and lower CLs for the overhead cost strictly from the salary CLs x 0.8;
2. Computing the contribution of these factors to the limits for the total cost as

   X_u (Salary + Overhead) = X_u (Salary) x 1.8

   X_{ℓ} (Salary + Overhead) = X_{ℓ} (Salary) x 1.8 ;

and then using the CLs in place of separate salary and overhead factors in the previously given equations for the CLs of X_{tot}.

An alternate, yet reasonable approach, while not statistically rigorous, generates similar confidence limits for the cost of Scenarios A and C. This approach is based on the fortuitous fact that straight addition of the costs and respective limits for the two large lopsided factors produces an aggregated cost whose limits are approximately symmetrically distributed. This two-factor aggregate value is \$1646K, the lower bound is \$900K less while the upper limit is greater by \$950K. Since the original uncertainties were estimated to give ∿ 95% confidence limits it would appear that \$1646K ± 925K should represent at least equivalent limits for the aggregate value. Combining (\$92K)^2, now assumed to represent $(2\sigma)^2$ for

aggregate cost of the two factors, with Σ_2, as defined, and taking the square root of the sum, gives ± \$970K. Thus the CLs for the total Scenario A cost are \$4180K and 6120K; which are not inconsistent with the limits obtained by the original approach used. Since the second approach (to determine the total cost CI for Scenarios A and C) is overly pessimistic (in that it combines two independent uncertainities by straight addition rather than rooting the sum of the squares) the CI estimates based on the first approach appear in the text.

FORM NBS-114A (1-71)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 74-506	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Development Of A National Anthropometric Data Base: A Preliminary Study Report			5. Publication Date June 1974 6. Performing Organization Code
7. AUTHOR(S) Harold L. Steinberg			8. Performing Organization NBSIR 74-506
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address National Bureau of Standards Institute for Applied Technology Washington, D.C. 20234			13. Type of Report & Period Covered Final 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

A study was made to determine the need for development of a Nationally Representative Anthropometric data base. Potential users and their needs are identified and the inability of existing anthropometric data to satisfactorily meet these needs is established. Three scenarios for developing a useful data base are considered. Two involve the use of biostereometrics while the third takes a relatively conventional approach to obtaining body dimensions. Conclusions relevant to each of these scenarios, as well as the potential advantages/disadvantages of each, are developed. Salient conclusions common to all three scenarios include: The need for a (R & D type) pilot study; the desirability of linking the actual anthropometric survey to a National Center for Health Statistics (NCHS) "Health and Nutrition Examination Survey" (HANES); and a data base development time of at least 7 years. Program costs, detailed in an appendix, ranged from \$2.4M to \$5.2M. Mechanisms for administering and funding this survey were considered briefly. An estimation of the optimal sampling dimensions for the proposed survey, based on clothing industry needs, is given.

17. KEY WORDS (Alphabetical order, separated by semicolons)

Anthropometric Survey, Biostereometric, Body-dimensions, National Data Base

18. AVAILABILITY STATEMENT	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[x] UNLIMITED.	UNCLASSIFIED	83
[ ] FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NTIS.	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price

USCOMM-DC 66244-P71